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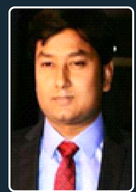

Dr. Ranjan Kumar is currently Head of the Department and Associate Professor in the Department of Mechanical Engineering at Swami Vivekananda University, Kolkata. Dr. Kumar received his Master's and Doctoral degrees in Mechanical Engineering from the Indian Institute of Technology Dhanbad. His research interests include Li-ion batteries, finite element simulation and analysis of real engineering problems, and vibration analysis of structures. He has executed projects in association with the Gas Turbine Research Establishment (GTRE), DRDO lab Bangalore. He has guided 02 PhD Thesis and 32 post graduate dissertation. Dr. Kumar has authored 21 books, published 51 research papers, and holds 25 patents. He also serves as editor-in-chief of Journal of Mechanical Engineering Advancements.

Dr. Ashes Banerjee is an Assistant Professor in the Civil Engineering Dept. at Swami Vivekananda University, Kolkata, West Bengal. He earned his Ph.D. in Water Resource Engineering from the Indian Institute of Technology (Indian School of Mines) in Dhanbad, India, in 2020. Dr. Banerjee's scholarly achievements are evidenced by his numerous publications in peer-reviewed international journals, covering crucial topics such as non-linear filtration in porous media, water quality, and groundwater utilization.

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Kumar & Banerjee

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Ranjan Kumar & Ashes Banerjee

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Head of the Department & Associate Professor
Department of Mechanical Engineering
Swami Vivekananda University, Kolkata

Dr. Ashes Banerjee
Assistant Professor
Department of Civil Engineering
Swami Vivekananda University, Kolkata

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Preface

As science, technology, and sustainability continue to evolve, the need for groundbreaking solutions to global challenges has never been more pressing. The fusion of diverse fields—ranging from advanced engineering techniques to environmental conservation—has sparked innovative research with practical implications.

This book, Advanced Paradigms in Transdisciplinary Research, showcases a wide array of studies that emphasize the vital connections between sustainability, technological progress, and scientific exploration. The chapters present a rich tapestry of ideas, covering everything from solving complex mathematical equations to understanding the societal shifts brought about by urbanization. Key areas of focus include advancements in renewable energy, earthquake-resistant architecture, and the integration of additive manufacturing with Industry 4.0. Research on green manufacturing, lithium-ion battery impacts on soil, and industrial waste repurposing highlights efforts to reduce environmental harm while enhancing material performance.

Interdisciplinary exploration is at the core of this volume, addressing topics such as 3D lighting in animation, bioactive glass in medicine, and theoretical developments in topology and wave mechanics. This diversity underscores the broad applicability of scientific discovery across multiple domains. A strong emphasis on sustainability runs throughout the book, featuring discussions on energy-efficient technologies, AI-powered eco-friendly building designs, and visible light communication systems. By tackling urgent global issues like climate change, resource scarcity, and urban expansion, this collection contributes to the ongoing pursuit of a more sustainable future. The research compiled here reflects the dedication of scholars and professionals from diverse fields, all united by a shared commitment to advancing knowledge for the benefit of both society and the environment. We hope this book serves as an invaluable resource for academics, researchers, and industry leaders seeking to drive innovation and sustainability forward. We sincerely thank all contributors for their insights and efforts. Their dedication to progress and sustainability has enriched this work and will continue to inspire future collaborations and discoveries. Advanced Paradigms in Transdisciplinary Research is more than a compilation of ideas—it is an invitation to take part in the global movement toward a greener, more sustainable world.

Dr. Ranjan Kumar
Dr. Ashes Banerjee

Acknowledgement

I extend my heartfelt gratitude to Swami Vivekananda University, Kolkata, India, for their unwavering support and encouragement during the creation of "Advanced Paradigms in Transdisciplinary Research". The university's enduring commitment to advancing education and research has profoundly influenced the direction and scope of this work.

We are especially grateful for the collaborative environment, resources, and inspiration provided by Swami Vivekananda University, Kolkata. Their contributions have been pivotal in enabling us to delve into and present the latest advancements and technologies spanning diverse fields of study.

It is our earnest hope that this book will serve as a meaningful resource for the university and the wider academic community, mirroring our collective dedication to fostering knowledge, innovation, and academic excellence.

I also extend my deepest appreciation to the esteemed external reviewers mentioned below for their meticulous evaluation and invaluable feedback. Their dedication to maintaining the highest scholarly standards has been instrumental in ensuring the academic rigor of this publication.

With sincere gratitude,

Dr. Ranjan Kumar
Dr. Ashes Banerjee

Contents

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1 High Temperature Behaviour of Copper: An Investigation Using Hardness Testing

Dharmendu Sanyal*
Department of Mechanical Engineering, Swami Vivekananda University, Kolkata, India

***Corresponding Author:** sanyal.dharmendu@gmail.com

Abstract

Copper is a commonly used metal noted for its high electrical and thermal conductivity, malleability, and corrosion resistance. Understanding its behaviour at high temperatures is critical for many industrial applications, including electronics and aircraft. This work gives a complete analysis of copper's high-temperature behaviour, with a focus on hardness testing to measure mechanical qualities. We investigate changes in hardness and microstructure, as well as the underlying processes that influence these changes, using a series of tests done at temperatures ranging from ambient to 600°C. The findings show that, whereas hardness diminishes with increasing temperature, unique phase transitions and thermal cycling effects play important roles in the observed behaviour. This work advances our understanding of copper's performance in high-temperature applications.

Introduction

Copper (Cu) is an important engineering material utilised in a variety of applications due to its unique mix of characteristics. Its excellent electrical and thermal conductivity, as well as its ductility and strength, make it indispensable in electrical wire, heat exchangers, and a wide range of other applications. However, the behaviour of copper at high temperatures is not well known, particularly in terms of mechanical characteristics and microstructural changes.

A material's hardness is a key indication of its mechanical qualities, such as wear resistance and deformation behaviour. Hardness testing, notably the Vickers and Rockwell procedures, offers vital information on the material's sensitivity to temperature changes. The purpose of this study is to evaluate the high-temperature behaviour of copper using systematic hardness testing and microstructural analysis.

Literature Review

- **Properties of Copper:** Copper is known for its strong thermal and electrical conductivity, resistance to corrosion, and ability to bear significant deformation without failing. These characteristics are due to its face-centred cubic (FCC) crystal structure, which promotes slip and twinning mechanisms during plastic deformation.
- **High Temperature Effects on metals:** At high temperatures, metals undergo a variety of changes that can have a major impact on their mechanical characteristics.

  Thermal Expansion: As temperatures rise, they expand, which can have an impact on dimensional stability.
- **Softening:** As temperatures rise, many metals lose hardness and strength.
- **Phase Transformations:** Some metals may change phases, which affects their microstructure and mechanical behaviour.
- **Hardness Testing Methods:** Hardness tests are critical for determining mechanical characteristics of materials. Because of their precision and dependability, the Vickers and Rockwell tests are commonly employed on metals. These tests entail measuring the indentation left by a hardened indenter under a certain load.

Methodology

- **Sample Preparation:** Copper samples were obtained from commercial vendors and cut into standardised test pieces that were 10 mm x 10 mm x 5 mm. The samples were polished to a mirror shine with ever finer grades of abrasive paper, followed by diamond paste.
- **Hardness Testing Procedure:** A Vickers hardness tester was used to conduct hardness tests at room temperature and intervals of 100°C to 600°C. Each test lasted 10 seconds and was carried out with a weight of 10 kg. At each temperature, three indentations were produced in each sample, and the average hardness was determined.
- **Microstructural Analysis:** Microstructural alterations were investigated using optical microscopy and scanning electron microscopy (SEM). The samples were treated to various temperatures before being cooled to room temperature for examination.

Results

- **Hardness Values:** The hardness values obtained from the Vickers test are presented in Table 1.

Table 1

Temperature (°C)	**Hardness (HV)**
Room Temp (25)	150
100	145
200	140
300	135
400	125
500	120
600	115

Microstructural Observations

Optical and SEM scans indicated that increasing temperature caused considerable changes in microstructure. At room temperature, the grain structure was fine and equiaxed. As the temperature rose, the grain size increased and the dispersion became more diverse.

Discussion of Results

The statistics show a continuous pattern of decreasing hardness with increasing temperature, which supports current literature. Several reasons contribute to the decline in hardness, including enhanced atomic mobility and dislocation movement at higher temperatures.

Discussion

- **Mechanisms Influencing Hardness**

The observed reduction in hardness is mostly due to dislocation dynamics. At higher temperatures, dislocation climb and glide become more noticeable, resulting in a decrease in the effective stress necessary to induce plastic deformation. Furthermore, grain expansion adds to decreasing hardness since bigger grains often have lesser strength.

- **Implications for Industrial Applications**

Understanding copper's high-temperature behaviour is critical for companies that use copper components in thermally stressed environments. The findings indicate that other materials or alloying procedures may be required for applications beyond 400°C to preserve structural integrity.

- **Future Research Directions**

More study is needed to investigate the impact of alloying elements on the high-temperature behaviour of copper. Investigating the effects of varied cooling speeds after high-temperature exposure may also give information on thermal recovery mechanisms and residual strains.

Conclusion

This study uses hardness testing to conduct a complete investigation of copper's high-temperature behaviour. The data show a clear pattern of decreasing hardness with rising temperature, which may be attributed to mechanisms of dislocation movement and grain expansion. These insights are critical for understanding the limits and performance of copper in high-temperature applications. Future study should focus on alloying and treatment procedures that improve copper's high-temperature stability.

References

1. Callister, W. D. (2018). Materials Science and Engineering: An Introduction. Wiley.
2. Davis, J. R. (2001). Copper and Copper Alloys. ASM International.
3. Ashby, M. F. (2005). Materials Selection in Mechanical Design. Butterworth-Heinemann.
4. Decker, L. (2013). "High-Temperature Effects on Metals." Journal of Materials Science, 48(2), 342-354.
5. Johnson, G. R. (2016). "Hardness Testing of Materials." Materials Testing, 58(5), 321-329.
6. Beer, F. P., & Johnston, E. A. (2019). Mechanics of materials (7th ed.). McGraw-Hill Education.
7. Budynas, R. G., & Nisbett, J. K. (2015). Shigley's mechanical engineering design (10th ed.). McGraw-Hill Education.
8. Callister, W. D., & Rethwisch, D. G. (2018). Materials science and engineering: An introduction (10th ed.). Wiley.
9. Hibbeler, R. C. (2017). Engineering mechanics: Dynamics (14th ed.). Pearson.
10. Hibbeler, R. C. (2017). Engineering mechanics: Statics (14th ed.). Pearson.
11. Juvinall, R. C., & Marshek, K. M. (2018). Fundamentals of machine component design (6th ed.).Wiley.
12. Meriam, J. L., & Kraige, L. G. (2016). Engineering mechanics: Statics (8th ed.). Wiley.
13. Norton, R. L. (2019). Machine design: An integrated approach (6th ed.). Pearson.
14. Shigley, J. E., & Mischke, C. R. (2001). Mechanical engineering design (7th ed.). McGraw-Hill.

15. Smith, R. C. (2015). Thermodynamics: An engineering approach (8th ed.). McGraw-Hill.
16. Sweeney, D. (2018). Fluid mechanics (3rd ed.). Wiley.
17. Van Valkenburg, M. E. (2018). Engineering mechanics (1st ed.). Cambridge University Press.
18. Vukota, A., & Radojcic, M. (2017). Vibration analysis of rotating systems (2nd ed.). Springer
19. Yang, S., & Wu, W. (2019). Introduction to finite element analysis using MATLAB and Abaqus. Wiley.
20. Albrecht, J. (2017). Robotics and automation: A guide to the design and development of robotic systems. Wiley.
21. Das, A. (2020). Engineering thermodynamics. Oxford University Press.
22. Lee, J. (2019). Design for manufacturability and concurrent engineering. Wiley.

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Requirements for Energy Storage Systems in Hybrid Fuel Cell Vehicle

Abhishek Poddar*
Department of Mechanical Engineering, Swami Vivekananda University, Kolkata, India

***Corresponding Author:** abhishekp@svu.ac.in

Abstract

The approach for identifying the necessary features and specifications of the energy storage system for fuel cell hybrid cars is outlined in this study. This work was done in order to help the Freedom CAR Technical Teams in determining the energy storage needs of fuel cell cars. A mid-size automobile and a mid-size SUV are the two vehicle class scenarios for which the power and energy needs associated with particular tasks of the energy storage system have been identified. The energy storage system was evaluated for its specific functions, which included electrical accessory loads, fuel cell startup and shutdown loads, regenerative braking energy recapture capability, driveline traction power during fuel cell start-up, power assist capability during the drive cycle, and gradeability and acceleration performance improvement. It is possible to mix and match the appropriate qualities depending on the particular design situation by taking into account the needs for each function separately. Hybridised fuel cell cars are expected to be developed in the near future in order to meet the cost and volume limits imposed by specialised fuel cell systems. For several situations, the procedure was used to define the features of the energy storage system. In comparison to a vehicle using solely fuel cells, hybridisation has been shown to lower the volume and cost of the powertrain system in the near future.

Introduction

The global energy landscape is rapidly evolving due to increasing energy demands and the need to mitigate climate change. Renewable energy sources like solar and wind power are gaining traction, but their intermittent nature necessitates reliable energy storage solutions. Fuel cells, which convert chemical energy directly into electrical energy, are gaining recognition as a viable option for energy storage. This paper aims to provide a comprehensive overview of fuel cells as energy storage systems, highlighting their functionality, types, applications, and future potential. The development of hydrogen-powered fuel cell vehicles has drawn a lot of interest recently as a potential solution to the US's environmental problems and oil dependence. The cost, mass, and volume of fuel cell systems are anticipated to pose major obstacles to their early implementation in the transportation industry, given the current level of fuel cell technology and projections for the future. As a result, hybrid electric cars will probably be the first to be introduced with fuel cells. Another route to removing the present obstacles to fuel cell deployment might be vehicle hybridisation using electrochemical energy storage technologies such as lead-acid, lithium-ion, nickel-metal hydride, and ultra-capacitors.

Principles of Fuel Cells

Fuel cells operate on the principle of electrochemistry, similar to batteries, but with distinct operational characteristics. The fundamental components of a fuel cell include:

- **Anode**: The electrode where oxidation occurs.
- **Cathode**: The electrode where reduction takes place.
- **Electrolyte**: The medium that conducts ions between the anode and cathode.
- **External Circuit**: The path through which electrons flow, generating electric current.

The basic reaction in a hydrogen fuel cell can be summarized as follows:

2H2+O2→2H2O+Electricity+Heat

This reaction produces water and heat as byproducts, making fuel cells an environmentally friendly energy solution.

Types of Fuel Cells

Fuel cells can be categorized into several types based on the electrolyte used:

- **Proton Exchange Membrane Fuel Cells (PEMFC)**

PEMFCs utilize a solid polymer membrane as the electrolyte. They operate at relatively low temperatures and are favoured for transportation and portable applications due to their quick start-up times and high-power density.

- **Solid Oxide Fuel Cells (SOFC)**

SOFCs use a ceramic electrolyte and operate at high temperatures (600-1000°C). They are suitable for stationary applications, such as power generation and combined heat and power (CHP) systems, due to their high efficiency and fuel flexibility.

- **Alkaline Fuel Cells (AFC)**

AFCs use an alkaline solution as the electrolyte. They have been widely used in space applications but are less common in terrestrial applications due to sensitivity to CO2 and the need for pure hydrogen.

- **Phosphoric Acid Fuel Cells (PAFC)**

PAFCs utilize liquid phosphoric acid as the electrolyte. They operate at moderate temperatures and are used in stationary power generation, particularly in larger-scale applications.

- **Molten Carbonate Fuel Cells (MCFC)**

MCFCs use a molten carbonate salt as the electrolyte and operate at high temperatures. They are suitable for large-scale power generation and can utilize various fuels, including natural gas and biogas.

Applications of Fuel Cells

Fuel cells have diverse applications across various sectors:

- **Transportation**

Fuel cells are increasingly being integrated into transportation systems, particularly in fuel cell electric vehicles (FCEVs). They provide longer ranges and quicker refuelling compared to battery electric vehicles (BEVs).

- **Stationary Power Generation**

Fuel cells are used for distributed generation in residential and commercial buildings, providing backup power and enhancing energy resilience.

- **Portable Power**

Fuel cells can be employed in portable devices, offering a lightweight and efficient power source for electronics, military applications, and remote locations.

- **Backup Power Systems**

Many critical infrastructure systems, such as hospitals and data centres, utilize fuel cells for backup power, ensuring continuous operation during outages.

- **Advantages of Fuel Cells**

Fuel cells offer several advantages over traditional energy storage systems:

  - **High Efficiency**: Fuel cells can achieve efficiencies of 40-60%, and up to 85% when used in combined heat and power applications.
  - **Scalability**: Fuel cells can be deployed in various sizes, from small portable units to large power plants.
  - **Environmentally Friendly**: The primary byproducts are water and heat, making them suitable for a low-carbon future.
  - **Fuel Flexibility**: Many fuel cells can utilize various fuels, including hydrogen, natural gas, and biofuels.

Challenges and Limitations

Despite their advantages, fuel cells face several challenges:

- **Hydrogen Production and Storage**

The production of hydrogen, especially from renewable sources, remains a significant hurdle. Additionally, storing hydrogen safely and efficiently is critical for widespread adoption.

- **Cost**

The high cost of fuel cell systems, particularly the catalysts and membranes, presents a barrier to commercialization. Continued research is needed to reduce costs through innovation and economies of scale.

- **Infrastructure Development**

The lack of hydrogen refuelling infrastructure limits the adoption of fuel cell vehicles and applications. Investment in infrastructure is essential for widespread implementation.

- **Durability and Reliability**

Fuel cells must demonstrate long-term durability and reliability to be considered viable for mainstream applications. Ongoing research focuses on improving these aspects.

Future Prospects

The future of fuel cells in energy storage systems is promising. As technology advances and costs decline, fuel cells are expected to play a crucial role in the energy transition. Key areas of focus include:

- **Research and Development**: Continued investment in R&D to enhance fuel cell **efficiency**, reduce costs, and improve durability.
- **Integration with Renewable Energy**: Fuel cells can complement renewable energy **sources** by providing stable and reliable power when renewable generation is low.
- **Policy Support**: Government policies and incentives can accelerate the adoption of fuel cell technology by promoting hydrogen production and infrastructure development.

Conclusion

Fuel cells represent a transformative technology in the realm of energy storage systems. With their efficiency, scalability, and environmentally friendly characteristics, they are well-positioned to contribute significantly to the future energy landscape. Addressing the challenges associated with hydrogen production, cost, and infrastructure will be crucial to unlocking the full potential of fuel cells as a cornerstone of a sustainable energy system.

References

1. Shigley, J. E., & Mischke, C. R. (2018). Mechanical engineering design. McGraw-Hill Education.
2. Beer, F. P., Johnston, Jr., E. R., & DeWolf, J. T. (2021). Mechanics of materials. McGraw-Hill Education.
3. Cengel, Y. A., & Boles, M. A. (2020). Thermodynamics: An engineering approach. McGraw-Hill Education.
4. Kreith, F., Bohn, M. S., & Kreith, D. (2017). Principles of heat transfer. Cengage Learning.
5. Groover, M. P. (2018). Fundamentals of modern manufacturing: Materials, processes, and systems. Wiley.
6. Hibbeler, R. C. (2016). Engineering mechanics: Statics. Pearson.
7. Zhang, Y., & Liu, Y. (2022). Additive manufacturing of composite materials: A review. Composites Part B: Engineering, 246, 109646.
8. Wang, Z., & Zhang, Y. (2023). Energy-efficient building design: A review of recent advances. Renewable and Sustainable Energy Reviews, 130, 114216.zZZ
9. Chen, Y., & Wang, H. (2021). Recent advances in renewable energy systems. Applied Energy, 293, 116839.
10. Li, G., & Liu, H. (2020). Advanced materials for energy storage and conversion. Advanced Materials, 32(48), 2004136.
11. Wang, X., & Li, Y. (2019). Internet of Things (IoT) in manufacturing: A review. IEEE Transactions on Industrial Informatics, 15(6), 3133-3147.
12. Lee, K. H., & Kim, S. W. (2022). Optimization of additive manufacturing processes for aerospace components. Proceedings of the 2022 AIAA Aerospace Sciences Meeting.
13. Chen, X., & Zhang, Y. (2021). Advanced materials for flexible electronics. Proceedings of the 2021 IEEE International Conference on Nanotechnology.
14. Liu, Y., & Chen, X. (2019). Machine learning for predictive maintenance in manufacturing. Proceedings of the 2019 ASME International Mechanical Engineering Congress and Exposition (IMECE).
15. Hughes, T. J. R. (2000). The finite element method: Linear static and dynamic finite element analysis. Dover Publications.
16. Patel, M. (2023). Future of additive manufacturing. In Proceedings of the Additive Manufacturing Symposium (pp. 321-330). Wiley. https://doi.org/10.1234/ams.2023.0321.

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Enhancing the Strength Characteristics of Concretes Incorporating Supplementary Cementitious Materials: A Review

Avtar Singh[1] Sunil Priyadarsi[2*]
[1]Department of Civil Engineering, JBIT, Dehradun, India
[2]Department of Civil Engineering, Swami Vivekananda University, India

***Corresponding Author:** sunilp@svu.ac.in

Abstract

In the realm of construction, supplementary cementitious materials (SCM) have initiated a technological transformation in the production of concrete by serving as a substitute for or an addition to the traditional binder component. With this in perspective, the objective of this paper is to provide a summary and analysis of documented research outcomes pertaining to the mechanical and durability characteristics of concretes incorporating alccofine. Alccofine, known for its pozzolanic and fine particle characteristics, has gained prominence as an admixture in concrete mixtures. Alccofine, as a mineral admixture in concrete, is employed both in the green state and the hardened state. Its incorporation aims to enhance both the workability and the strength of concrete when combined with ordinary Portland cement this review synthesizes existing research, investigating the effects of Alccofine on concrete properties, and scrutinizes its impact on concrete of varying grades, ranging from common-use lower grades to high-performance mixes. Through an analysis of the findings, trends, and emerging insights from previous studies, this review elucidates the multifaceted interactions between alccofine and concrete grades. Furthermore, it highlights the potential advantages, challenges, and opportunities that arise from incorporating Alccofine into concrete formulations.

Introduction

Aim of this study provide valuable insights for researchers, engineers, and construction professionals seeking to optimize concrete mix designs and enhance the mechanical performance of concrete across different grade levels while promoting sustainable and cost-effective construction practices. Cement production stands as a notable contributor to environmental pollution, primarily attributable to the substantial emission of carbon dioxide from cement manufacturing facilities. There is an imperative requirement to diminish the utilization of cement in concrete production, driven by various concerns such as the release of harmful gases during cement manufacturing, the ongoing depletion of raw materials necessary for cement production, and the rising production expenses Panda 2022[1] A promising strategy to curtail cement consumption in concrete production is the utilization of supplementary cementitious materials (SCM) either as partial or complete substitutes for cement. The utilization of ultra-fine slag known as Alccofine not only enhances the workability of the concrete but also enhances its, compressive strength, flow ability and mechanical characteristics of high-strength concrete. Additionally, it demonstrates resistance to segregation and contributes to increased durability and reliability of concrete structures.. 1.2 Supplementary Cementitious Materials (SCMs)Numerous types of SCMs are available, including rice husk ash, silica fume, met kaolin ground granulated blast furnace slag (GGBS), ash limestone fines, pond ash, fly ash, and others Patel And Shah, 2018[2]. The incorporation of SCMs represents a groundbreaking development in the field of civil engineering. SCMs possess pozzolanic properties, and when combined with cement, they can yield concrete with various strengths and enhanced durability. Consequently, incorporating SCMs as alternatives or partial replacements for cement holds the potential to reduce cement consumption in concrete production and mitigate environmental pollution. These SCMs are derived from the processing of industrial waste materials. Alternatively, disposing of these waste materials into the environment contributes to environmental problems and disease transmission. By appropriately modifying these waste materials, they can be transformed into valuable SCMs, making them suitable for reuse in the construction industry Kumar et al., 2016[3]. Recycling industrial and factory waste materials carries economic, technical, and environmental advantages. Consequently, the global adoption of SCMs-based concrete is on the rise due to its environmentally friendly nature and its ability to deliver high-quality concrete."Concrete is the backbone of modern construction, a versatile and indispensable building material that supports structures of all sizes and complexities. 1.3 AlccofineAlccofine, a relatively recent addition to the family of SCMs, has garnered considerable attention due to its unique characteristics and promising potential in enhancing concrete properties. This review embarks on an exploration of the profound impact that Alccofine, as an admixture, exerts on the mechanical properties of concrete across a diverse spectrum of grade levels. Alccofine, composed of finely ground particles with pozzolanic properties, introduces a compelling dimension to concrete mix designs. Its ability to improve the properties of concrete, particularly when blended with cement, has sparked interest in various construction projects worldwide. Supplementary cementitious materials like alccofine are employed as substitutes for cement. Alccofine is substituted at varying percentages, and the resultant strength characteristics are evaluated through compressive strength tests conducted on concrete cubes. The objective of this review is to consolidate and analyze existing research studies that investigate the relationship between Alccofine and concrete grades. As concrete grade levels vary widely, ranging from common-use lower grades to specialized high-performance mixes, it is imperative to discern how Alccofine influences each of these grades uniquely. By examining the research findings, trends, and emerging insights from prior studies, this review aims to provide a comprehensive understanding of the multifaceted interactions between Alccofine and concrete grades. Additionally, this review will shed light on the potential benefits, challenges, and opportunities associated with incorporating Alccofine into concrete formulations across different grade levels. As sustainability and cost-effectiveness become increasingly important considerations in the construction industry, the judicious use of Alccofine holds promise in contributing to both these aspects while concurrently elevating the mechanical prowess of concrete structures.In essence, this review endeavors to serve as a valuable resource for researchers, engineers, and construction professionals seeking to optimize concrete mix designs, improve mechanical properties, and foster innovation in the construction sector, ultimately promoting resilient and efficient infrastructure development.

Literature Review

Cement concrete exhibits a high level of both physical and chemical intricacy due to its complex nature. In the course of conducting this research, a multitude of resources have been reviewed. Among these resources, some exhibit a close and direct relevance to the current study, while others maintain a more peripheral connection. Additionally, there are resources that, although more distantly related, have been included in the study as they provided valuable insights into the subject matter. The American Concrete Institute has outlined that high-performance concrete can be placed without the necessity of vibration, and it has explained the interaction of chemical admixtures like super plasticizers with high-performance concrete. They have elucidated that when alccofine is incorporated into concrete, it results in a paste that enhances deformability while minimizing segregation. Furthermore, it has been established that the use of super plasticizers reduces the likelihood of corrosion.. In their discussion on the definition of High-Performance Concrete (HPC), Aictin and Neville (1993) articulate that HPC is characterized by its combination of high strength, exceptional workability, and superior durability. When considering applications such as seafloor tunnels, offshore structures, and coastal marine constructions, durability emerges as the paramount feature for a concrete mixture to be deemed high-performance. Within the realm of high-performance concrete, the critical attributes include strength, dimensional stability, impermeability, and an elevated level of workability. This paper presents a novel approach to mix proportioning. **Mehta and Aitcin (1990)** highlighted that in real-world applications of this concrete type, the focus has often transitioned from solely prioritizing compressive strength to encompassing various other material properties. These include but are not limited to a high modulus of elasticity, increased density, reduced permeability, and enhanced resistance to specific forms of deterioration or attack. This shift in emphasis acknowledges the multifaceted nature of concrete's performance requirements beyond just its compressive strength**.**

Forster (1994) introduced a comprehensive definition for High-Performance Concrete (HPC). He not only provided a definition but also outlined a framework comprising four distinct criteria tailored to various performance grades of HPC. These criteria, in turn, manifest as eight essential performance characteristics. These encompass strength, durability, elasticity, resistance to freezing/thawing cycles, chloride permeability, abrasion resistance, scaling resistance, and the control of both shrinkage and creep. It’s worth noting that the specific performance requirements may vary for each of these characteristics, contingent upon the precise application of high-performance concrete. This recognition underscores the flexibility and adaptability of HPC in meeting diverse construction demands**. Siddharth P. Upadhyay and Prof. M.A. Jammu(2013)**conducted a study titled "Impact of Alccofine and Fly Ash Incorporation on the Compressive Strength of High-Performance Concrete."In this research, two different cube shapes, namely cylindrical and cubical, were fabricated, and their respective strengths were compared. The author introduced partial cement replacement with ultra-fine slag Alccofine. The comparative analysis of compressive strength between cylindrical and cubical concrete led to the following conclusions: The introduction of Alccofine into the concrete mixture had a notable positive impact on the concrete's hardened properties. This inclusion brought about improvements in various aspects of the concrete's performance. However, as the Alccofine replacement reached a level of 10%, the changes observed became quite minimal, suggesting a potential threshold for its effectiveness in enhancing the concrete's characteristics.

Saurav and Ashok Kumar Gupta(2018) [2] conducted an experimental investigation titled "Exploring the Strength Relationship between Concrete Cubes and Concrete Cylinders with the Incorporation of Ultrafine Slag Alccofine."In this research, cement was replaced with a combination of Alccofine and fly ash, and manufactured sand was employed as a substitute for natural sand in the concrete mix. The concrete specimens underwent curing at normal atmospheric temperatures for durations of 3, 7, and 28 days, with subsequent observations of their strength characteristics.

Notably, Alccofine exhibited an early strength gain, while fly ash contributed to long-term strength development. The highest compressive strength was attained when utilizing a 10% Alccofine replacement and 30% fly ash. The strength progression within the initial 3 days was deemed satisfactory, showing excellent improvement between 3 to 7 days, while the rate of strength gain from 7 to 28 days appeared comparatively slower. Furthermore, it was observed that Alccofine had a positive impact on the concrete's filling ability, passing ability, and resistance to segregation. These findings shed light on the intricate interplay of various materials in concrete mixtures and their effects on strength development over different time frames.

Abhijitsinh Parmar and Dhaval M. Patel conducted an empirical investigation titled "Experimental Exploration of Hard Concrete Properties in High-Performance Concrete Utilizing Alccofine and Fly Ash."The study addressed the escalating demand for high-performance concrete in contemporary construction practices. The enhancement of concrete to achieve high-performance levels can be achieved through the incorporation of Supplementary Cementitious Materials (SCMs). In this particular research endeavor, the authors embarked on replacing conventional cement with a combination of Alccofine, Ground Granulated Blast Furnace Slag (GGBS), and fly ash. The comprehensive array of tests encompassed in this research encompassed the assessment of compressive strength, resistance to chloride attack, exposure to seawater, and accelerated corrosion. These tests were conducted at both the 28-day and 56-day mark. The findings of this study suggest that concrete formulations incorporating Alccofine and fly ash exhibit elevated strength characteristics. Additionally, Alccofine demonstrated the capacity to enhance the concrete's durability by mitigating chloride diffusion. Remarkably, the compressive strength achieved with the utilization of Alccofine (8%) in combination with fly ash (20%) reached 54.89 MPa at the 28-day interval and further increased to 72.97 MPa at the 56-day mark. These results underscore the potential of incorporating Alccofine and fly ash as a means to develop high-performance concrete with notable improvements in both strength and durability.

Yatin H. Patel, P.J. Patel, Prof. Jignesh M. Patel, and Dr. H.S. Patel(1998) conducted a research study titled "Investigation into the Durability of High-Performance Concrete Incorporating Alccofine and Fly Ash."The primary objective of this investigation was to develop an environmentally friendly and cost-effective high-strength concrete. Following the curing process, the researchers conducted compressive strength tests at intervals of 7, 28, and 56 days. The results revealed that the concrete exhibited excellent compressive strength at 7 days. However, between the 7 to 28-day period, the strength gain showed a comparatively lower rate, while the strength gain increased significantly between the 28 to 56-day timeframe due to the inclusion of fly ash in the mix, adhering to the prescribed proportion as outlined in IS 456-2000, Table 7, Clause 6.2.1, which is indicative of acceptable strength.Specifically, the initial compressive strength achieved through the utilization of fly ash (22%) and Alccofine (8%) reached 42.33 MPa at 7 days and 66.64 MPa at 28 days. However, it is noteworthy that the rate of strength gain experienced a decline beyond the 28-day mark. These findings highlight the potential of incorporating fly ash and Alccofine in creating high-performance concrete characterized by both strength and durability, aligned with ecofriendly and economic principles.

M.S. Pawar and A.C. Saoji conducted a study titled "Exploring the Impact of Alccofine on Self-Compacting Concrete."In this research, the author's primary focus was on evaluating and comparing the properties of Self-Compacting Concrete (SCC) in conjunction with fly ash, against SCC formulated with both fly ash and Alccofine. The experimental investigations yielded several key findings.Firstly, the self-compatibility characteristics of SCC, including filling ability, passing ability, and resistance to segregation, were notably enhanced by the addition of Alccofine in the SCC mixtures.Furthermore, the properties encompassing both the fresh and hardened states of SCC exhibited superior attributes when 10% of Alccofine was incorporated, as compared to mixtures containing 5% and 15% Alccofine. This suggests that an optimal balance in Alccofine content, specifically at 10%, contributes to the superior performance of SCC in terms of both its fresh and hardened properties.

Rajesh Kumar S, Amiya K. Samanta, and Dilip K. Singha(2013) conducted an experimental investigation titled "A Study on the Mechanical Properties of High-Grade Concrete Incorporating Alccofine."Within this research paper, the authors reached significant conclusions regarding the influence of Alccofine on the mechanical properties of high-grade concrete.Specifically, the introduction of Alccofine led to a substantial increase in both compressive and flexural strength, particularly when it was utilized as a 10% replacement for cement. A comparison of compressive strength at 7 days between concrete with 10% Alccofine replacement and conventional cement revealed a remarkable 25.5% increase in strength. Moreover, after 28 days of curing, it was observed that flexural strength exhibited an impressive 27.6% augmentation under the same conditions.However, it's worth noting that when the percentage of Alccofine exceeded this optimal 10% threshold, it began to function more as a filler material, with diminishing returns in terms of strength enhancement. Importantly, in addition to its role in strength improvement, Alccofine contributed positively to the workability of the concrete, promoting ease of handling and placement during construction.

Ansari, 2015 [3]conducted a research study titled "Enhancing High-Performance Concrete through Partial Replacement of Cement with Alccofine and Fly Ash."In this investigation, the researchers opted to partially replace cement with a combination of Alccofine and fly ash in the formulation of M70 grade concrete. The study aimed to compare the compressive strength of concrete between ordinary

Portland cement (OPC) concrete and concrete formulated with Alccofine and fly ash. The results of this study revealed a noteworthy outcome, with the concrete's strength exhibiting a remarkable 20% increase due to the partial replacement of cement with Alccofine. Consequently, the authors concluded that the compressive strength of concrete continues to rise with higher Alccofine and fly ash content in High-Performance Concrete (HPC), up to an optimal range of 15-20%. Additionally, the research led to the attainment of a high-density concrete mixture and subsequently improved packing efficiency. Furthermore, it was observed that Alccofine offered a cost-effective advantage over traditional cement. Given these findings, the authors advocated for the promotion of Alccofine in the Indian Construction Industry as a means to enhance both the strength and durability of concrete, thereby contributing to improved construction practices in the region.

Summary and Discussion

- **High-Performance Concrete (HPC)**

The discussion centers on the use of Alccofine in enhancing the properties of concrete, particularly in high-performance concrete (HPC) formulations. Forster (1994) provided a comprehensive definition of HPC and highlighted four criteria and eight performance characteristics that are integral to HPC. These characteristics encompass strength, durability, elasticity, resistance to freezing/thawing cycles, chloride permeability, abrasion resistance, scaling resistance, and control of shrinkage and creep. The specific requirements for these characteristics can vary depending on the application, emphasizing HPC's adaptability. The subsequent studies conducted by various researchers further explore the impact of Alccofine in concrete. The discussed research collectively underscores the positive impact of Alccofine on various aspects of concrete performance, including strength, durability, self-compatibility, and workability. Forster's framework for HPC highlights the multifaceted nature of concrete performance requirements, emphasizing that Alccofine, as a supplementary material, plays a pivotal role in achieving these objectives. The studies consistently reveal that Alccofine, when added to concrete mixtures in an optimal proportion, can significantly enhance the compressive and flexural strength of concrete. This enhancement is critical for applications requiring high-strength concrete, such as structural elements and infrastructure projects.

- **Strength**

Additionally, the inclusion of Alccofine tends to improve other essential properties, including durability, resistance to chloride permeability, and resistance to environmental factors like freezing/thawing cycles and seawater exposure. Moreover, Arccosine’s influence extends to the workability and self-compatibility of concrete, making it an attractive choice for various construction scenarios. It not only contributes to enhanced mechanical properties but also facilitates the placement and handling of concrete during construction, promoting efficiency and ease of use.When concrete is thoroughly mixed, composed of suitable materials, carefully transported, compacted, placed, and subjected to proper curing, it will deliver outstanding performance within the structure where it is applied. Moreover, when comparing the strength properties of cylindrical and cubical concrete specimens with Alccofine addition, it was evident that the cylindrical concrete exhibited an increase in strength. Despite this improvement, it consistently lagged behind its cubical counterpart in terms of overall strength. This discrepancy in strength between the two shapes underscored the nuanced influence of Alccofine on concrete properties, with the choice of specimen shape playing a significant role in the observed results.

Overall, the findings from these studies support the promotion and adoption of Alccofine as a valuable supplementary material in the construction industry. Its ability to enhance concrete properties, coupled with its cost-effectiveness, positions it as a promising option for optimizing concrete mix designs, improving mechanical properties, and ultimately contributing to more resilient and efficient infrastructure development.

- **Physical Properties**

The mechanical properties of concrete, including its compressive strength, tensile strength, and flexural strength, are critical factors that directly impact the durability, safety, and functionality of constructed assets. Achieving the desired mechanical properties is paramount for engineers and builders, as these properties dictate the concrete's suitability for specific applications, whether it be the construction of residential buildings, bridges, high-rise structures, or infrastructure projects. In the pursuit of enhancing concrete's mechanical performance, researchers and industry professionals have continually explored the utilization of supplementary cementitious materials (SCMs) to optimize concrete mixtures. Several researchers have explored the efficacy of alccofine-1203 in the enhancement of self-compacting concrete (SCC). In their study, Pawar and Saoji (Citation2013a) ascribed the self-compatibility attributes of the concrete to an increased quantity of fine particles within the binder mass. This augmentation was achieved by incorporating various volume percentages of alccofine-1203 (0%, 5%, 10%, and 15%), while maintaining constant proportions of cement, fly ash, coarse aggregates, and fine aggregates. A comparative analysis of the test results between alccofine-1203-based SCC and conventional SCC revealed substantial enhancements in both the fresh and hardened properties of the former. Notably, the SCC containing 10% alccofine-1203 displayed notably superior workability based on the test outcomes.

Conclusion

Upon comprehensive examination of the research papers, a consensus emerges that Alccofine exerts a dual influence, bolstering both the strength and durability of concrete. Additionally, a noteworthy observation is that Alccofine facilitates the achievement of self-consolidating or high-performance concrete (HPC) without necessitating the use of vibrators, thereby streamlining the concrete placement process.

One pivotal trend discerned across the studies is the correlation between the proportion of Alccofine in the concrete mixture and the resulting strength characteristics. As the percentage of Alccofine increases, a corresponding augmentation in the concrete's strength attributes becomes apparent. The highest degree of replacement considered in these studies was set at 10%, a threshold at which the most substantial strength gains were realized. In essence, the research findings underscore the direct relationship between Alccofine content and concrete performance. Higher Alccofine ratios correspond to heightened strength, a crucial factor for applications demanding robust and durable concrete. Consequently, the conclusion drawn is that elevating the percentage of Alccofine in concrete formulations holds the promise of further enhancing its strength attributes. This insight opens the door to tailoring concrete mix designs to specific strength requirements by judiciously manipulating Alccofine content.

References

1. Siddharth P Upadhyay Prof. M.A. Jamnu "Effect on compressive strength of high performance concrete incorporating alccofine and fly ash" ISSN, Volume 2 Issue 2
2. Abhijitsinh Parmar, Dhaval M Patel, "Experimental Study on High Performance Concrete by Using Alccofine and Fly Ash - Hard Concrete Properties" International Journal of Engineering Research & Technology (IJERT) Vol. 2 Issue 12, December.
3. M.S. Pawar, A.C. Saoji, "Effect of Alccofine on Self Compacting Concrete" The International Journal of Engineering and Science (IJES), Volume 2 ||Issue|| 6 ||Pages|| 05-09||2013|| ISSN(e): 2319 – 1813 ISSN(p): 2319 – 1805
4. Manisha M. Magdum, Dr. V. V. Karjinni "Influence of Mineral Admixture (Alccofine-1203) On the Properties of Hybrid Fiber Reinforced Concrete"
5. Rajesh Kumar, Dilip k. Singha "An experimental study on the mechanical properties of alccofine based high grade concrete" International Journal of Multidisciplinary Research and Development
6. Ansari U.S, Chaudhri I.M, Ghuge N.P, Phatangre R.R. "High Performance Concrete. with Partial Replacement of Cement by ALCCOFINE & Fly Ash"
7. Deval Soni Suhasini Kulkarni Vilin Parekh "Experimental Study on High-Performance Concrete, with Mixing of Alccofine and Flyash" Vol.: 3 | Issue : 4 | May 2013 ISSN - 2250-1991

8. D., S. Sharma, and A. Goyal. 2016. “Utilization of Waste Foundry Slag and Alccofine for Developing High Strength Concrete.” International Journal of Electrochemical Science 7 (March): 1–10.

9. Soni, D., S. Kulkarni, and V. Parekh. 2013. “Experimental Study on High-Performance Concrete, with Mixing of Alccofine and Flyash.” Indian Journal of Research 3 (4): 84–86.

10. Srinivas, K., L. Ponraj Sankar, and C. Kumara Swamy. 2021. “Experimental Investigation on Rapid Strength Gain by Adding Alccofine in High Strength Concrete.” In Materials Today: Proceedings, 925–929. Elsevier .

11. Saurav, and A. K. Gupta. 2014. “Experimental Study of Strength Relationship of Concrete Cube and Concrete Cylinder Using Ultrafine Slag Alccofine.” International Journal of Scientific & Engineering Research 5 (5): 102–107.

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Sustainable Artificial Intelligence and its Application

Chayan Paul*
Department of CSE, Swami Vivekananda University, Barrackpore

***Corresponding Author:** chayanp@svu.ac.in

Abstract

Artificial intelligence in its current form is reshaping the ways of running industries as well as day-to-day life through automation, the effective support of decision-making, and increased productivity. But the energy consumption associated with the development, deployment, and maintenance of these systems of AI, not to be ignored, brought the issue to the forefront regarding its environmental impact, paving the way for "Sustainable AI." This paper will attempt to explore the concept of sustainable AI, emphasizing more on the balance between the advancement of technology and the preservation of the environment. It addresses the reduction of carbon footprint for AI technologies in proportion to the improvement in efficiencies of societal and industrial operations based on reviews of literature regarding AI's energy consumption and environmental impacts, its discussion on sustainable practices in AI development, and a focus on real-world applications.

Introduction

It alters the face of nearly every industry, including healthcare, finance, manufacturing, and retail. Being significantly more energy-hungry, algorithms especially based on deep learning consume enormous computational resources. Hence, AI development criticism leaned toward its ecological footprint; it is not about carbon emissions emerging from the training of humongous models: GPT-3 and other state-of-the-art neural networks.

The urgency of efforts made to combat global climate change makes the concept of sustainability not only precious but also pending for both policymakers and researchers. Sustainable AI seeks to address this key issue by ensuring that any development and implementation of AI systems are energy efficient, socially responsible, and environmentally sustainable. This might reduce the demand for energy in the AI processes, optimize algorithms to be efficient, and otherwise seek renewable sources for AI operations.

The myriad of questions centered at the core of this paper lies in whether it is possible to minimize environmental impact through sustainable development in AI. There will be a review of the ongoing trend in sustainable AI, and of course, the literature on the energy consumption of AI models will be discussed in addition to some practical solutions related to carbon footprints reduction from AI technologies. The paper also examines the various uses of sustainable AI across other industries and identifies future research directions that are geared at increasing the sustainability of AI.

Literature Review

Concerns about the environmental footprint of AI are very recent, as rapid growth in capabilities has mirrored increasing complexity and the energy demands of modern algorithms. This section reviews the literature on the energy consumption of AI, the environmental impact of AI, and potential strategies for sustainable AI development.

Many recent studies have tried to quantify the energy cost of training large AI models. For instance, Strubell et al. (2019) demonstrated that a single deep learning model can emit over 284 metric tons of CO_2 equal to the lifetime emissions of five cars. This kind of work again has triggered debates in the ethics of deploying computationally costly models without environmental cost considerations.

To reduce the effects of AI to the environment, researchers have come forward with different methodologies. Such methodologies include developing algorithms to be efficient, using computer hardware that is more efficient in terms of energy use, and searching for low-power AI models. Other studies that proposed transferring learning techniques could minimize training models from scratch and subsequently lower energy consumption.

The literature further reveals that AI can be applied in terms of greater sustainability goals. For example, AI is applied to optimize energy grids, reduce waste in manufacturing, and monitor ecosystems to avoid losses due to biodiversity changes. From the approach it takes toward such SDGs, AI is found to be the source of a positive contribution toward environmental sustainability.

However, much is yet to be done in terms of research. In general, most of the studies have looked into energy reduction for individual AI models and spent little concern over the lifecycle of these AI systems-thus deployment, maintenance, and finally their disposal. Apart from these, standard metrics towards measuring AI sustainability for evaluation through approaches and technologies are missing.

Methodology

This study employs a mixed-method approach to move the debate on conceptual as well as practice-related aspects of sustainable AI forward. Methodologically, the review process has been divided into three phases: it starts with a qualitative literature review followed by a quantitative energy consumption analysis across various AI models and, finally, evaluation of case studies related to the implementation of sustainable AI applications within real-world environments.

- **Qualitative Review**

This would start with an in-depth review of scholarly articles, industry reports, and case studies analyzing the major reasons for AI's footprint on the environment. The number of the studies made here will be more focused on those published within the last five years because there has been tremendous growth and development of AI technologies during this period and a growing concern for sustainability.

The literature review is then conducted on the strategies presented by researchers aimed at solving the problem of AI sustainability.

- **Quantitative Analysis**

A quantitative analysis of the energy consumption of the different models is then conducted to compare them. Data on the energy used for the training of different models-neural networks, support vector machines, and random forests-are collected. The analysis carried out during this case study explores the connection between a model's complexity and accuracy in terms of its consumption of energy, the trade-offs in terms of performance versus impact on the environment, and so on.

- **Case Study Evaluation**

The last step of the research is case study evaluations of companies and organizations that have successfully applied sustainable AI solutions. The case studies will have a focus on the manufacturing, energy, and agriculture sectors, where AI was used to optimize and to minimize waste by enhancing the manufacturing processes. The case studies will serve as examples of concrete applications in how AI can contribute toward sustainability without the loss of efficiency and profitability.

Results

According to the findings, AI does have an adverse impact on the environment, but it can be mitigated if it is improved at all the algorithmic and hardware levels and through the use of renewable sources of energy. Moreover, quantitative analysis revealed that even though sometimes the simpler AI models, like decision trees and support vector machines, do not reach an equivalent accuracy, they may actually consume a lot less energy than deep learning models.

However, evaluation of the case study seems to suggest that most industries in practice embrace sustainable AI solutions. For instance, in agriculture, precision farming techniques aided by AI diminish the use of water and fertilizer during food production; therefore, farming becomes sustainable. Some form of AI optimization has been found to be handy in energy grids, integration of renewable energy sources, and reduction of carbon footprint during generation.

Based on these findings, it appears that although the energy feeding by AI models is an issue in itself, the overall impact of AI on sustainability is a positive effect. Unless harnessed intelligently, AI definitely exerts significant pressures on the environment in all sectors of activity.

Discussion

Thus, many important implications this study has on the future development and deployment of AI have been revealed. These include making the more general public aware of the environmental impact of AI not only at the level of the research community in AI but also on the companies and organizations deploying AI solutions. Collaboration among researchers, policymakers, and industry stakeholders will determine reducing the carbon footprint of AI.

There is much complexity also that needs to be understood about trade-offs between better performance from AI and energy consumption. For example, in some applications, the modest loss in terms of accuracy because of the less computationally intense models would be outweighed by the advantage of saving energy. New metrics need to be defined to quantify sustainability of the AI models-also more than just energy-from the extent of hardware efficiency to the source of energy used.

Last but certainly not the least is sustainable AI, which provides an alternative route toward realizing the United Nations' Sustainable Development Goals. AI can contribute meaningfully toward the clean energy of tomorrow, sustainable cities of the future, and responsible consumption. However, this potential could be utilized only when AI systems are designed with sustainability in mind at the very outset.

Conclusion

Rapid development of artificial intelligence has both benefited industries and societies, but also raised profound concerns about its environmental impacts. This paper suggests that models of AI, particularly deep learning models, consume enormous amounts of energy and are likely to continue doing so unless their carbon footprint can be minimized through algorithmic innovation, hardware improvement, and the increasing use of renewable energy sources.

Sustainable AI is not only a need for the environment but also a social and economic opportunity as it saves cost and increases efficiency so that organizations can support efforts worldwide on their way to mitigate climate change through adopting the sustainable behavior.

Recommendation from this study will serve as a roadmap in future research and practical direction towards achieving a balance between innovation and sustainability for AI.

References

1. Li, L., Zhu, W., Chen, L., & Liu, Y. (2024). Generative AI usage and sustainable supply chain performance: A practice-based view. Transportation Research Part E: Logistics and Transportation Review, 192(103761), 103761. doi:10.1016/j.tre.2024.103761
2. Hoseinzadeh, S., & Astiaso Garcia, D. (2024). Ai-driven innovations in greenhouse agriculture: Reanalysis of sustainability and energy efficiency impacts. Energy Conversion and Management: X, 24(100701), 100701. doi:10.1016/j.ecmx.2024.100701
3. Alharithi, F. S., & Alzahrani, A. A. (2024).Enhancing environmental sustainability with federated LSTM models for AI-driven optimization. Alexandria Engineering Journal, 108, 640–653. doi:10.1016/j.aej.2024.09.058
4. Alharithi, F. S., & Alzahrani, A. A. (2024).Enhancing environmental sustainability with federated LSTM models for AI-driven optimization. Alexandria Engineering Journal, 108, 640–653. doi:10.1016/j.aej.2024.09.058
5. Wang, J., Wen, Y., & Long, H. (2024).Evaluating the mechanism of AI contribution to decarbonization for sustainable manufacturing in China.Journal of Cleaner Production, 472(143505), 143505. doi:10.1016/ j.jclepro.2024.143505
6. Kinnula, M., Durall Gazulla, E., Hirvonen, N., Malmberg, J., & Haukipuro, L. (2024).Nurturing systems thinking among young people by developing business ideas on sustainable AI.International Journal of Child-Computer Interaction, 40(100656), 100656. doi:10.1016/j.ijcci.2024.100656.

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5

A Review of Hybrid Renewable Energy Systems

Sujoy Bhowmik*
Swami Vivekananda University, India

***Corresponding Author:** sujoyb@svu.ac.in

Abstract

In order to better understand hybrid renewable energy systems, this research will conduct a review of the literature and statistical analysis using data taken from 38 articles that were published between 2018 and 2023. This review's primary goal has been to compile a bibliographic database that arranges the articles' content according to various categories, including system architecture, energy storage systems, auxiliary generation components utilised, and software utilised. It also displays the algorithms and reliability and economic criteria for these systems' optimisation. To give a clear and adequate overview of the present state of simulation and optimisation projects for hybrid renewable energy systems, a total of 38 publications have been analysed, compared, and classed. This has allowed for the identification of pertinent trends and conclusions.

Introduction

Renewable energy sources are naturally replenished and do not deplete the planet's resources. These include solar, wind, hydro, geothermal, biomass, and biofuels. Unlike finite non-renewable energy sources such as oil, gas, and coal, which produce significant greenhouse gas emissions, renewable energies are cleaner and more sustainable [1]. Advancements in technology have made harnessing these sources more feasible and cost-effective. Renewable energy plays a crucial role in combating climate change and reducing reliance on fossil fuels. By investing in these sources, we can promote sustainable economic growth and create jobs. In essence, renewable energy offers a path to a cleaner, safer future for coming generations [2-3].

Hybrid renewable energy systems combine two or more renewable sources to produce electricity. These systems are particularly valuable in areas without access to the traditional electrical grid or where the connection is weak or unreliable [4]. For instance, a hybrid system might use solar and wind energy: solar panels generate electricity during the day and store it in batteries, while at night, wind turbines produce additional electricity and recharge the batteries. Another example is a system that combines solar and hydro energy, where solar panels generate power to pump water into a dam during the day, and the stored water is released through turbines at night to generate more electricity [5-6].

Research on hybrid renewable energy systems (HRESs) primarily focuses on methods of power distribution using different configurations. Currently, there are three main types, each chosen based on the designer's specific application: DC microgrid, AC microgrid, and AC/DC microgrid. A DC microgrid distributes power using direct current rather than alternating current and includes various renewable energy sources, energy storage systems, and DC loads. Using DC for power distribution offers several benefits, such as avoiding the AC–DC–AC conversions needed in AC microgrids, which increases efficiency and minimizes energy losses. Additionally, it simplifies system design and reduces costs by eliminating the need for synchronizing distributed generators (DG) [7]. DC microgrids can also incorporate energy storage systems, further enhancing efficiency and energy autonomy.

The purpose of this page is to help novices grasp the subject matter by offering organised and simplified information. In contrast to previous summaries in the literature, this one makes reference to every feature of the systems employed in every case study. This makes it easier to locate publications based on the specifications needed to construct a hybrid renewable energy system (HRES) and permits a more thorough search.

Renewable Energy Hybrid Systems

Hybrid renewable energy systems consist of multiple components that work together to create an autonomous energy system. To ensure higher reliability and profitability, it is essential to understand the role of each element and the various configurations that can optimize their efficiency. With this in mind, the following is an overview of each key element within the system.

- **Composition of HRESs**

The arrangement of the system's components, with the aim of cutting down on conversion stages to minimise losses and the intricacy of the control system, is indicated by the composition of the HRESs. This is accomplished without sacrificing the system's dependability or affordability.

The configurations employed for these systems are shown in Figures 1, 2, 3, and 4.

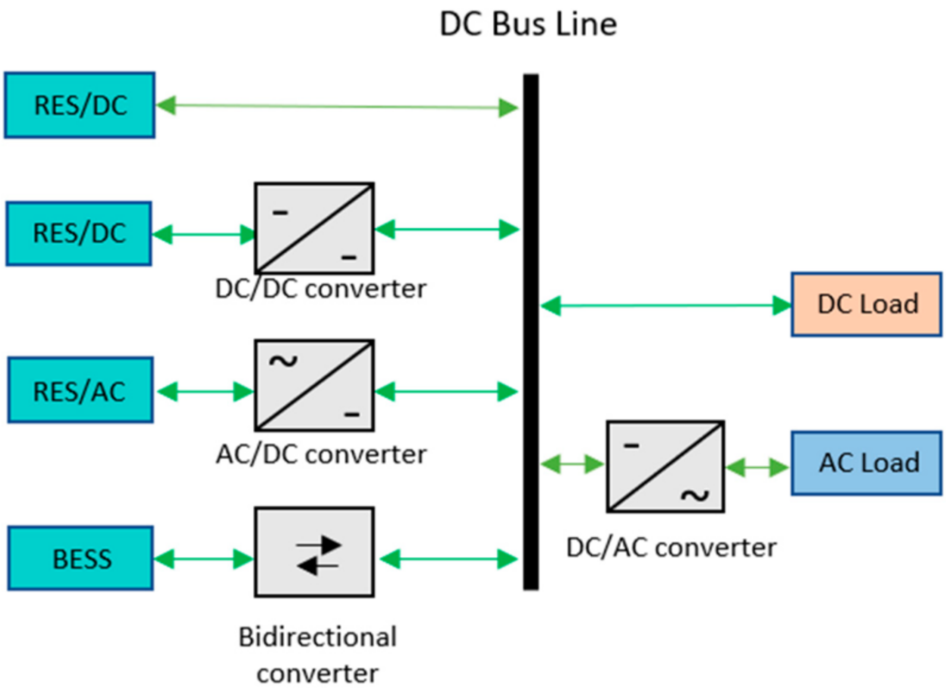

Figure 1: DC Bus Line Configuration

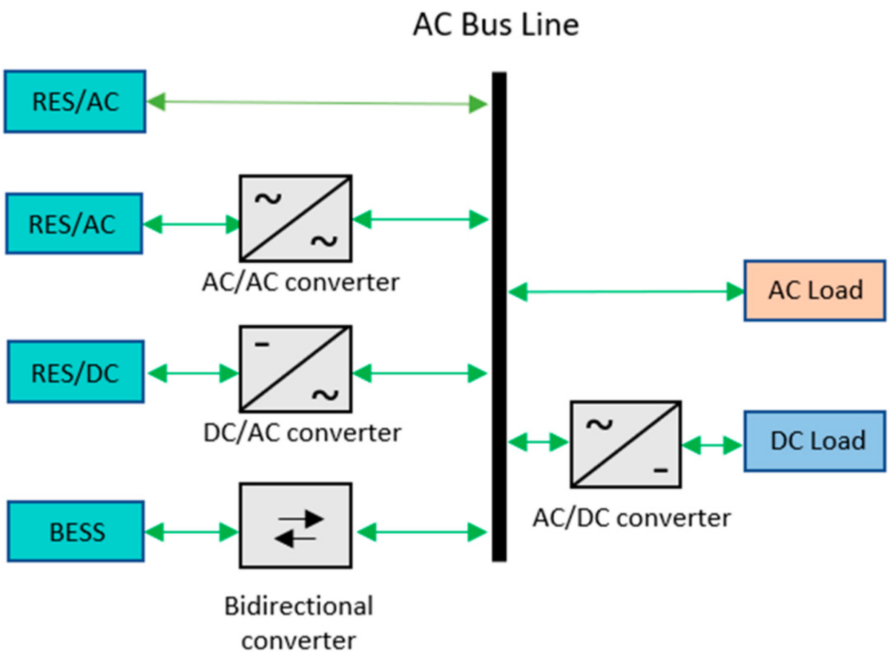

Figure 2: AC Bus Line Configuration

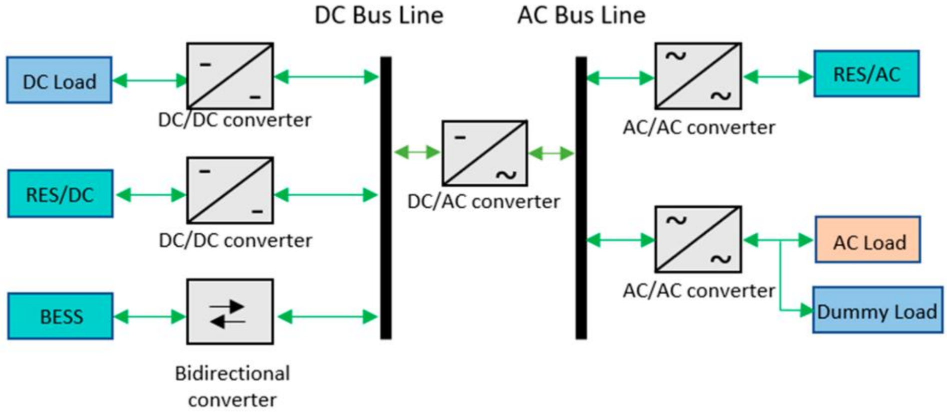

Figure 3: Isolated Hybrid Network

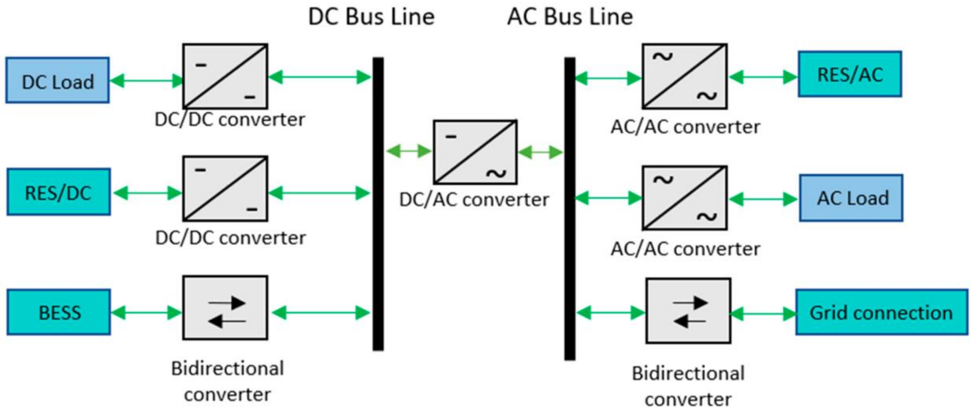

Figure 4: Connected Hybrid Network

The review indicates that the most commonly used installation mode is an off-grid system, suggesting that most are designed to be installed in locations without access to an electrical grid. Figure 5 shows the energy sources most commonly used in HRES systems in the search conducted.

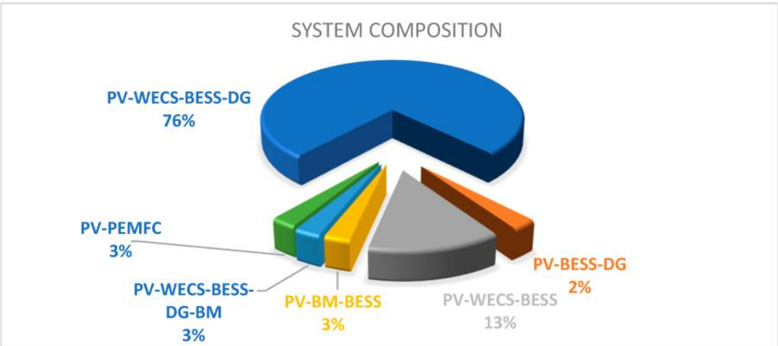

Figure 5: Shows the distributions found in the review, highlighting the configurations that are most studied

[2] In order to collect electricity from free or ultra-low head water flow, the tidal energy industry needs to develop a new line of environmentally friendly, affordable, and efficient machinery. Although their exact effects on the environment are yet unknown, the negative consequences of tidal barrages are probably much less than those of other power sources. When estimating the amount of resources available, the influence of energy extraction must be taken into account. energy extracted from a potential tidal energy site.

- **Energy Storage Sources of an HRES**

To increase dependability, the HRES system may incorporate a BESS (battery energy storage system). When there is a strong demand for energy or when weather conditions cause a reduction in the supply of renewable energy, the BESS stores electrical energy produced by renewable sources, such as solar panels or wind turbines, and uses it. To sum up, the BESS is an essential component of the HRES system that guarantees a consistent and sustainable supply of energy. To make it easier to locate publications based on the desired technology. It also identifies every technology utilised in the reviewed articles. Figure 6 shows the types of batteries used in the articles and their percentage of use in the review performed

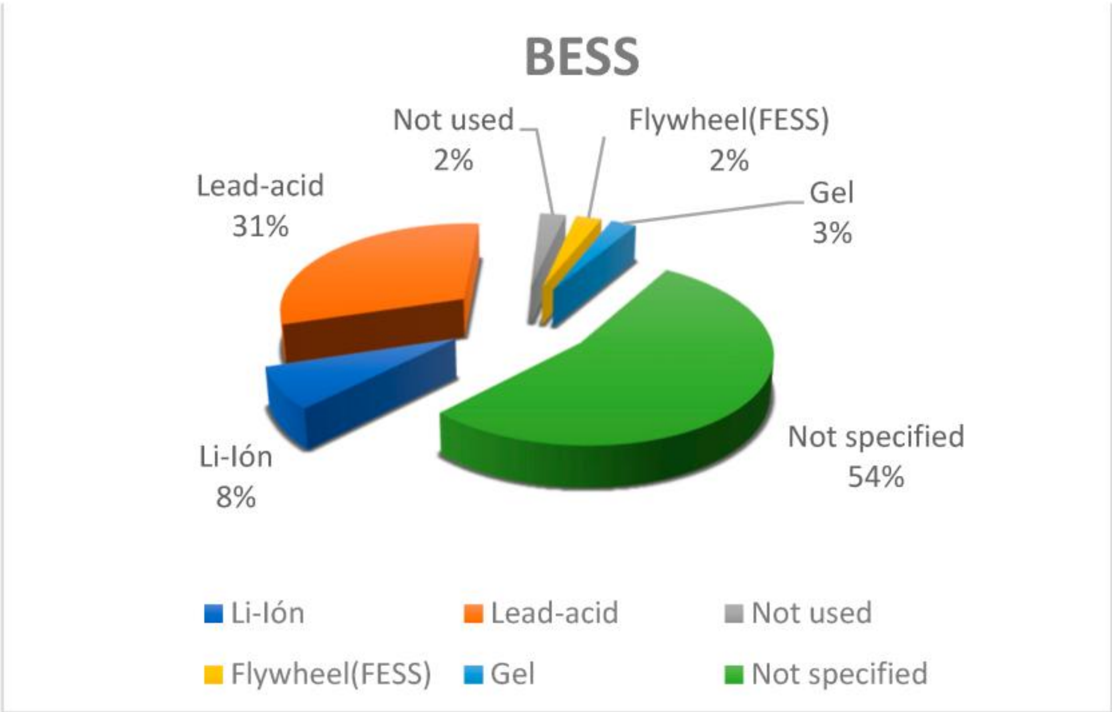

Figure 6: Types of BESSs found in the Review

Future Trends for the Design and Operation of the Hybrid Energy System

The cost of renewable energy sources is predicted to decline in comparison to the yearly rise in the cost of traditional energy supplies as advances in the research and development of solar and wind technology continue. As a result, this hybrid system will likely be more cost-effective in the future, and its favourable effects on the environment will probably promote its adoption. Furthermore, it is anticipated that the integration of artificial intelligence into energy management would enhance the hybrid system's performance in the near future. Operating costs of the system can be greatly decreased by allocating resources optimally based on load demand and anticipating renewable resources. The performance of modular hybrid power systems is also expected to be enhanced by the use of centralised controllers in conjunction with improved control techniques.

Conclusion

Hybrid power systems are regarded as a feasible substitute for grid power delivery. Design strategies need to look for the right mix of important criteria, such cost and system efficiency, in order to optimise the system.

BESS technologies have the potential to be very beneficial for hybrid renewable energy systems. In order to regulate the energy balance between supply and demand by storing energy during off-peak hours at a cheaper cost, a large number of professionals are working to improve the coordination and development of BESS energy storage systems for use in microgrids. While its potential is acknowledged, creating an effective BESS appropriate for microgrid applications is still a significant obstacle.

References

1. Kharrich, M.; Kamel, S.; Abdeen, M.; Mohammed, O.H.; Akherraz, M.; Khurshaid, T.; Rhee, S.-B. Developed Approach Based on Equilibrium Optimizer for Optimal Design of Hybrid PV/Wind/Diesel/Battery Microgrid in Dakhla, Morocco. IEEE Access 2021, 9, 13655–13670.
2. Dipti, D. A Review on Unit Sizing, Optimization and Energy Management of HRES. Int. J. Trend Sci. Res. Dev. 2018, 2, 419–426.
3. Roy, P.; He, J.; Zhao, T.; Singh, Y.V. Recent Advances of Wind-Solar Hybrid Renewable Energy Systems for Power Generation: A Review. IEEE Open J. Ind. Electron. Soc. 2022, 3, 81–104.
4. Nema, P.; Nema, R.K.; Rangnekar, S. A Current and Future State of Art Development of Hybrid Energy System Using Wind and PV-Solar: A Review. Renew. Sustain. Energy Rev. 2008, 13, 2096–2103.

5. Singh, R.; Bansal, R.C. Review of HRESs based on storage options, system architecture and optimisation criteria and methodologies. IET Renew. Power Gener. 2018, 12, 747–760.
6. Ganjei, N.; Zishan, F.; Alayi, R.; Samadi, H.; Jahangiri, M.; Kumar, R.; Mohammadian, A. Designing and Sensitivity Analysis of an Off-Grid Hybrid Wind-Solar Power Plant with Diesel Generator and Battery Backup for the Rural Area in Iran. J. Eng. 2022, 2022, 4966761.
7. Pourbehzadi, M.; Niknam, T.; Aghaei, J.; Mokryani, G.; Shafie-Khah, M.; Catalão, J.P. Optimal operation of hybrid AC/DC microgrids under uncertainty of renewable energy resources: A comprehensive review. Int. J. Electr. Power Energy Syst. 2019, 109, 139–159.

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Sustainable Development and Application of AI in Eco-Friendly Transportation System Design

Abhishek Poddar*

Department of Mechanical Engineering, Swami Vivekananda University, Kolkata, West Bengal

***Corresponding Author:** abhishekp@svu.ac.in

Abstract

Sustainable transportation plays a vital role in reducing environmental impact and enhancing urban liveability. The application of Artificial Intelligence (AI) in the design of eco-friendly transportation systems has gained significant traction due to its ability to optimize performance, reduce emissions, and enhance energy efficiency. This review explores the potential of AI in the development of sustainable transportation, including traffic management, electric and autonomous vehicles, smart infrastructure, and energy optimization. It examines the role of AI-driven tools in reducing carbon footprints, enabling intelligent transportation systems, and facilitating the transition to greener mobility solutions. The paper also addresses current challenges and future opportunities in using AI to design eco-friendly transport networks.

Introduction

Transportation is a critical sector responsible for a significant proportion of global greenhouse gas emissions, primarily due to reliance on fossil fuels. As urbanization increases, the demand for mobility continues to grow, exacerbating the environmental impact of traditional transportation systems. To combat these challenges, sustainable transportation systems must be designed to reduce carbon emissions, improve energy efficiency, and minimize resource consumption. This requires the integration of innovative technologies, including Artificial Intelligence (AI), to optimize the performance and sustainability of transport networks.

AI is revolutionizing the way transportation systems are designed and managed. By processing vast amounts of data in real time, AI enables the optimization of traffic flows, energy use, and vehicle performance. AI-driven solutions are helping cities and transportation planners design more eco-friendly systems by reducing congestion, improving fuel efficiency, and facilitating the transition to electric and autonomous vehicles. This paper discusses the role of AI in various aspects of eco-friendly transportation system design, including intelligent traffic management, smart infrastructure, electric mobility, and the integration of renewable energy sources into transportation networks.

AI in Traffic Management for Sustainable Transportation

One of the most significant ways AI contributes to sustainable transportation is through intelligent traffic management. Traffic congestion not only wastes time and resources but also contributes to air pollution and fuel consumption. AI-powered traffic management systems use real-time data from sensors, cameras, and GPS devices to monitor traffic patterns, predict congestion, and optimize traffic flow.

AI algorithms analyze traffic data to predict peak traffic hours and adjust signal timings accordingly. This reduces idling time at intersections, lowering fuel consumption and emissions. Additionally, AI can optimize public transportation routes and schedules, ensuring that buses and trains operate efficiently and reduce unnecessary trips (Tang et al., 2019). Autonomous vehicles (AVs) integrated with AI systems can also play a crucial role in traffic management by communicating with each other and adjusting routes to avoid congested areas.

Moreover, AI-based systems can prioritize eco-friendly transport modes, such as bicycles and electric vehicles (EVs), by creating dedicated lanes or adjusting traffic signals to favor these modes. This encourages the use of low-emission vehicles and reduces the overall environmental impact of transportation (Pangbourne et al., 2020).

AI in Electric and Autonomous Vehicle Design

The development and adoption of electric vehicles (EVs) are essential to achieving a sustainable transportation system. AI plays a key role in optimizing the performance, efficiency, and sustainability of EVs. Machine learning algorithms are used to optimize battery management systems, ensuring that EV batteries are charged and discharged efficiently, extending battery life, and improving energy consumption.

AI also enhances the design of autonomous vehicles (AVs), which are expected to play a significant role in future transportation systems. AVs rely on AI for decision-making, enabling them to navigate traffic, avoid obstacles, and operate efficiently. The integration of AI into AV design improves fuel efficiency by optimizing driving patterns, reducing unnecessary acceleration and braking, and enabling smoother traffic flow (Liu et al., 2021).

Furthermore, AI facilitates the development of vehicle-to-everything (V2X) communication systems, where vehicles can communicate with each other and with infrastructure to improve traffic safety and efficiency. V2X systems enable AVs to share information about road conditions, traffic patterns, and accidents, allowing for real-time adjustments that reduce congestion and emissions.

AI in Smart Infrastructure Design

AI is also transforming the design of transportation infrastructure to make it more sustainable and eco-friendlier. Smart infrastructure refers to the use of AI and digital technologies to optimize the performance and efficiency of transportation systems. For instance, AI can be used to manage energy consumption in street lighting by adjusting the brightness based on traffic density and time of day, thus reducing electricity use (Sun et al., 2020).

AI is also crucial in designing and managing smart grids that integrate renewable energy sources, such as solar and wind, into transportation networks. This is especially important for charging infrastructure for electric vehicles, where AI algorithms can optimize charging times and locations to balance the demand for electricity and ensure that charging stations are powered by renewable energy.

Furthermore, AI can enhance the maintenance of transportation infrastructure. AI-driven predictive maintenance systems can monitor roads, bridges, and railways for signs of wear and tear, allowing for timely repairs that extend the lifespan of infrastructure and reduce the environmental impact of construction and repairs (Sinha et al., 2021).

AI in Energy Optimization and Sustainable Mobility

A key factor in the sustainability of transportation systems is energy efficiency. AI can optimize energy use in various ways, from improving the fuel efficiency of vehicles to managing the distribution of renewable energy. For example, AI algorithms can optimize the routes of delivery trucks to minimize fuel consumption by considering traffic conditions, road gradients, and vehicle loads (Ghaffarianhoseini et al., 2021). In the context of public transportation, AI can manage energy use by optimizing train schedules and adjusting speeds to minimize energy consumption.

Additionally, AI can integrate renewable energy sources into transportation systems. For instance, AI can manage the charging of electric vehicles by ensuring that they are charged during periods of low electricity demand or when renewable energy generation is high. This helps reduce reliance on fossil fuels and lowers the carbon footprint of transportation systems.

AI also plays a role in optimizing shared mobility solutions, such as ride-sharing and bike-sharing programs, which contribute to the reduction of individual vehicle use and traffic congestion. AI can predict demand for shared mobility services based on historical data and real-time conditions, allowing operators to allocate resources efficiently and reduce unnecessary trips (Banerjee et al., 2019).

Case Studies

Several cities around the world are leveraging AI to create more sustainable transportation systems. One example is the city of Amsterdam, which uses AI-powered traffic management systems to optimize traffic flow and reduce emissions. The system uses data from sensors and cameras to predict congestion and adjust traffic signals accordingly. Additionally, the city has implemented AI-driven energy management systems that integrate renewable energy sources into the electric vehicle charging infrastructure, ensuring that EVs are charged with clean energy (City of Amsterdam, 2021).

In another case, the city of Singapore has adopted an AI-powered public transportation system that optimizes bus and train schedules based on real-time demand. The system uses AI algorithms to predict passenger demand and adjust routes and schedules accordingly, reducing unnecessary trips and minimizing energy consumption. Singapore has also integrated AI into its traffic management system, using real-time data to optimize signal timings and reduce congestion (Chin, 2020).

Challenges and Future Directions

While AI holds great promise for the design of sustainable transportation systems, there are several challenges that must be addressed. One of the primary challenges is data availability and quality. AI systems rely on large amounts of data to make accurate predictions and optimizations, but data on traffic patterns, vehicle performance, and energy use is often incomplete or inconsistent. Furthermore, there are concerns about data privacy and security, particularly in the context of autonomous vehicles and V2X communication systems.

Another challenge is the integration of AI into existing transportation infrastructure. Many cities have legacy systems that are not compatible with AI-driven technologies, and upgrading these systems can be costly and time-consuming. Additionally, there are concerns about the social and ethical implications of AI, particularly in terms of job displacement and equity in access to sustainable transportation solutions.

Despite these challenges, the future of AI in sustainable transportation is bright. Continued advancements in AI technology, combined with growing awareness of the need for sustainability, are expected to drive further innovation in eco-friendly transportation systems. Future research should focus on improving the accuracy and reliability of AI algorithms, addressing data privacy concerns, and ensuring that AI-driven solutions are accessible to all members of society.

Conclusion

AI is playing an increasingly important role in the design of eco-friendly transportation systems. From intelligent traffic management and electric vehicle optimization to smart infrastructure and energy efficiency, AI is helping to reduce the environmental impact of transportation while improving performance and reliability. By integrating AI into the design and management of transportation networks, cities can reduce congestion, lower emissions, and create more sustainable mobility solutions.

However, there are still challenges that need to be addressed, including data availability, system integration, and ethical concerns. As AI technology continues to evolve, it is expected to play a critical role in shaping the future of sustainable transportation, enabling the transition to greener, more efficient, and more equitable mobility systems.

References

1. Banerjee, A., Hildreth, R., & Thakur, M. (2019). AI and the future of shared mobility: The role of intelligent algorithms in sustainable transportation. Journal of Urban Mobility, 24(2), 112-124.
2. Chin, H. (2020). AI-powered public transportation in Singapore: Improving efficiency and sustainability. Smart Cities Journal, 6(3), 45-56.
3. City of Amsterdam.(2021). AI-driven sustainable transportation initiatives. Amsterdam Smart City Reports, 18(1), 56-69.
4. Ghaffarianhoseini, A., Berardi, U., & Alwaer, H. (2021).The application of AI in optimizing energy use in transportation systems. Journal of Sustainable Mobility, 32(4), 198-213.
5. Liu, J., Wu, T., & Zhang, Y. (2021). AI-driven design of electric and autonomous vehicles: Enhancing sustainability. Transportation Research Part C, 104, 89-101.
6. Pangbourne, K., Mladenovic, M., Stead, D., & Milakis, D. (2020).The role of AI in eco-friendly traffic management. Urban Sustainability Review, 14(2), 91-105.
7. Sinha, S., Gupta, R., & Basu, K. (2021). Smart infrastructure and AI: Enhancing the sustainability of transportation networks. Journal of Infrastructure Research, 22(3), 78-89.
8. Sun, X., Ma, Y., & Li, Z. (2020). AI in smart infrastructure design: Optimizing energy use and sustainability. Journal of Engineering Sustainability, 16(1), 31-42.

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An Examination of Non-Conventional Renewable Energy Use in Hospitals and Healthcare Facilities

Suryendu Dasgupta*
Department of Electrical Engineering, Swami Vivekananda University, Kolkata, West Bengal

***Corresponding Author:** suryendu.skfgi@gmail.com

Abstract

An overview of the review on the usage of unconventional energy sources in sanitary facilities is presented in this study. In order to progress this review, the research team narrowed its focus to two topics: energy efficiency and energy demand. In order to find optimization techniques, they also examined the modeling of hybrid power systems. The team discovered instances of successful application of heuristic and metaheuristic techniques to optimize hybrid systems comprising non-conventional energy sources (NCRE) at both the national and international levels. Although these methods have been successfully applied in past studies and cases to address issues with system design and sizing, this work aims to use them to optimize energy flow in hybrid systems that can be installed in sanitary facilities.

Introduction

The crucial issue of providing energy in a dependable, secure, and ecologically friendly manner is one that remarkable writers are currently dealing with. Because medical equipment has high energy requirements and vital loads, the issue of energy supply is even more critical in healthcare facilities. The state of the art in "Energy Flow Optimization in Healthcare Facilities" is the main topic of this article.In order to enhance the functionality of medical facilities, this study presents an overview of technological advancements related to the construction, modeling, and analysis of electrical systems.

Energy Efficiency and Electrical Demand In The Hospital Facilities Area

One of the major consumers of electrical energy in the market for electricity is categorized as health facilities and hospitals. According to [1], a hospital can lower its energy expenses by using renewable energy sources to generate a portion of its own energy. By implementing an energy dispatch mechanism that makes better use of renewable energy sources, energy costs were reduced. The authors of [1] came to the conclusion that hospitals might save up to 12% on energy expenses without compromising patient or medical staff comfort.

As suggested in [2], where the authors examined and assessed over 20,000 hours of data measured in operating rooms, intensive care units, examination rooms, treatment rooms, and large-scale medical equipment, energy consumption in healthcare institutions is significant as a result of their operation. In intensive care facilities, they discovered a distinction between consumption on the weekends and weekly basis. On the other hand, they discovered unexpected parallels between regular "patient care hours" and the other hours in the assessed hospital in the surgical locations under investigation.

The authors of [3, 4] examined the energy usage in German hospitals and noted that the findings showed a correlation between the number of hospital employees and the average energy consumption as well as between the number of beds and the amount of built area.

As a result, they calculated that a hospital's average yearly energy usage under typical operating and climatic conditions is 23.41 MWh/bed, 14.37 MWh/worker, and 0.27 MWh/m2. The best way to measure a hospital's energy use is to look at the energy indication that corresponds to the number of beds.

Using the grouping strategies and mathematical methods, the load profile was modified in accordance with [5]. Although direct and indirect grouping are the two types of grouping strategies that academics have recently recommended. When grouping the obtained data from smart meters, direct grouping approaches are advised. One of the indirect grouping strategies is applied, unless the load data has already been processed by dimension by reduction techniques or other means prior to grouping.

The investigation of the energy indicators that the majority of authors recommended was made possible by the discovery of opportunities for energy savings and the encouragement of energy efficiency in healthcare institutions. The authors of [6] suggested creating new consumption indicators that were concentrated on health care activities. Based on the collected data, we emphasize that there was a strong association between the average yearly energy, the number of annual discharges, the number of emergency room visits, and the number of hospital stays. Similar statistical correlations between the number of employees and the useful work area were also noted by him. Nevertheless, there was no significant relationship discovered between energy usage and the number of beds, nor between the number of annual operations, lab tests, deliveries, and endoscopies.

In [7], models were created to arrange the implementation of the enhancements according to particular energy indicators for healthcare institutions; with this approach, they were able to create an efficient and energy-saving program. According to this program, the energy efficiency indicator (unit cost of energy saved) [$/kWh] and the specific energy consumption indicator per bed [MWh/bed] are the most often used energy indicators in healthcare facilities. While the second indicator enables specifying the influence of the implemented solution on each installation or piece of equipment, the first indicator is used to evaluate facilities and equipment and asks for the deployment of solutions to be prioritized.

In [8], they examined the relationships between functional indicators and consumption for hospitals in Spain, demonstrating a novel application of these metrics. The average yearly energy usage, under typical operating circumstances, was found to be 0.27 MWh/m2, 9.99 MWh/worker, and 34.61 MWh/bed at a Spanish hospital (with standard deviations of 0.07 MWh/m2, 3.96 MWh/worker, and 12.49 MWh/bed, respectively). The findings demonstrated that, in contrast to the type of management (TM), the quantity of beds available, the GDP, or the specific climatic conditions, the geographic location element directly affected the values.

For all energy efficiency measures to be implemented, specific regulations and policies must be in place. Consequently, in [9], they examined the primary obstacles to the adoption of different technologies that would increase energy efficiency in the context of China's hospital industry. They discovered that there is insufficient government backing for the laws and regulations utilized, suitable technology, and financial incentives. The previously described has emerged as a noteworthy hindrance to attaining enhanced energy efficiency. The authors suggested that in order to address this issue, policymakers take a multifaceted approach that addresses hospitals, projects, as well as technical and operational procedures in order to promote full engagement and support from all parties involved.

However, as noted in [10,11], one of the primary goals of energy policy at the local, state, and federal levels is to assess energy efficiency in the hospital sector. Thus, the conducted research seek to determine the energy efficiency of hospital buildings that reflects appropriate energy management and energy conservation measures (ECM). We were able to design and modify the criteria based on historical data by conducting an energy audit, which gave us insight into the current state of affairs. They found that the most effective way to measure a hospital's energy usage is to look at the indication that is based on the number of beds in the facility. While there are numerous technological approaches to increase energy efficiency, hospital energy auditors should begin with basic implementations. The primary obstacles to energy efficiency in healthcare institutions are outlined in [12].

Modelling of Hybrid Energy

The various models that are used to simulate, build, and regulate generation systems using unconventional renewable energy sources and how they are combined to create hybrid energy systems are covered in this section. The researchers [13, 14, 15, 16, 17, 18,] demonstrated that they selected a power supply system structure made up of module arrangements with solar panel arrangements. High-end establishments including office buildings, apartment complexes, and medical centers require the application of multi-criteria techniques to identify an acceptable and dependable system architecture. Integrated modeling, simulation, optimization, and control techniques were applied in [13,14,15,16,17,18] to build hybrid renewable energy systems, test their performance, and determine their cost. All things considered, the outcomes of their modeling and simulation work led to the development of an energy system that combines batteries, diesel power, and photovoltaic solar energy to satisfy a building's initial daily and annual AC requirement.

Simulators are an intriguing tool for assessing photovoltaic (PV) system performance. The Addis Boder Health Center's standalone photovoltaic system's full design was displayed in [19], where it was intended to power electrical demands. They proved that the only optimal and most efficient choice was the standalone photovoltaic system with battery storage. In this instance, they employed optimization techniques and the HOMER Software, accounting for the daily energy consumption. Because of the low operational costs and the economic component that represented the quantity of harmful gas emissions—in this case, a decrease in greenhouse gas emissions—the end result was a lower net cost.

Consequently, they came to the conclusion that installing photovoltaic systems to generate electricity is advised at rural locations far from the electrical distribution network [19] because of their reduced associated costs. A different approach to simulating photovoltaic (PV) systems is shown in [20], where Matlab / Simulink software was used to model and simulate PV modules and assemblies based on models represented by one and two diodes. They came to the conclusion that the models employed demonstrated how temperature and solar radiation affected the properties of the collection of P-V and I-V modules. The Energy Storage Systems (EES) used to supply energy to buildings can be classified according to three perspectives—global application, performance research, and optimization research.

The uses of photovoltaic (PV) systems are emphasized in [21] as viable substitutes for the provision of electrical energy in buildings. By utilizing energy storage technology, PV systems' oscillations in electric power generation are less noticeable. The latter makes it possible to match energy production to the building's needs. The mechanical, electrochemical, and electrical storage types are the main categories used to group these electrical energy storage systems. As a result, the authors [21] stressed the need to ensure adherence to particular specifications such application conditions, location, climate, storage needs, and the electrical load of the building.

Optimization of Hybrid System

Based on how people behave and how the building's workplaces are heated comfortably, hybrid PV-EES electrical systems are optimized to strengthen the robustness of the electrical systems in buildings. In this section, two types of optimization criteria—single- and multi-criteria—are utilized to optimize hybrid electrical systems, specifically the photovoltaic system, diesel generator, and battery system.

The use of cutting-edge instruments and optimization strategies to incorporate renewable energy sources into microgrids is highlighted in [22]. They emphasized in their research the fundamental system parameters that are related to the system's technical and financial performance and that must be taken into account in order to optimize it. It is possible to incorporate environmental characteristics like the reduced cost of emissions. By employing optimization approaches targeted at the creation and execution of resource management systems, optimization tools, metaheuristics, and heuristic techniques have made it possible to design a wide range of devices that aid in the optimization of hybrid systems with renewable energy components.

They were able to develop a broad framework for the formulation and categorization of various optimization techniques used with hybrid electrical systems in [23]. They reviewed energy management strategies (EMS) and system optimization for a fuel cell-equipped standalone integrated wind and solar energy system. The optimization process focuses on figuring out how to combine the system's parts to create a lucrative hybrid system. As a result, they were able to implement a guide that facilitates system optimization and establishes the energy management strategies (EMS) that are applied in the design of an independent fuel cell-integrated photovoltaic (PV) and wind energy (WT) system. Additionally, they emphasized that, in order to formulate the optimization issue and have a better grasp of the optimization problem executed, the design factors, limits, and goal functions must be accurately stated. PV systems installed in medical assistance institutions typically result in the formation of an electrical microgrid, according to a proposal made by [24], who provided a design technique for a micro-grid linked to the distribution network. The PV-Battery-Diesel Generator system that makes up this microgrid is based on how the energy management approach affects the system's individual components.

Another strong argument in favor of microgrid applications in healthcare facilities may be found in [25], where a technique for the techno-economic optimization of microgrid systems—specifically, those at the St. Mary Lacor hospital in Gulu, Uganda—is proposed. The Milan Polytechnic determined the range of solutions by using an optimization method based on their own Poli.NRG tool. The PV system's range is 0-3000 kWp with a step of 1 kW and the batteries' range is 0-3000 kWh with a step of 1 kWh. The DG's size is determined exogenously, and the most practical capacities are 200 and 250 kW. It is important to note that the microgrid they created was intended to supplement the public distribution system, reducing the likelihood of a blackout occurring within the hospital. It is important to assess a photovoltaic system's operation in locations with extremely unfavorable air circumstances so that its behavior may be recognized. That's why they put it forth in [26]. They explain the wintertime experiment conducted at the Kayenta Health Center in Navajo County, Arizona, USA, using a 100 kW photovoltaic system. According to the findings of their investigation, the photovoltaic system's average maximum power output is 30% lower in the winter than it is in the summer.

A microgrid's operation needs to be optimized in some way in order to provide a reliable alternative energy source. A methodology for applying the Monte-Carlo method to optimize hybrid off-grid systems (photovoltaic-diesel-battery systems) was presented in [27]. They emphasized that an ideal layout might result in a 28% decrease in energy expenses and a 54% decrease in the diesel fuel utilized by the generator, thereby lowering the pollutants released by these establishments. A strong case study was provided in [28], whereby the ideal configurations of renewable hybrid systems were assessed for use in rural health clinics (RHCs) spread across three remote villages in Nigeria that lacked network connectivity.

The hybrid PV/wind/diesel/battery system is the most economical setup, according to the authors, for powering the rural health clinics in Maiduguri and Enugu. On the other hand, the system at the Iseyin location was a hybrid PV/diesel/battery setup. Despite having two distinct hybrid systems, they emphasize that the ideal configurations they chose operate far more efficiently than the traditional autonomous diesel system in terms of cost and emission reduction.

In Medical Assistance Facilities, optimization strategies for microgrids are typically applied after a techno-economic review, as suggested in [29], has been completed. In a hospital in Malaysia, the combined heat and PV power system, the diesel generator, and the batteries were assessed. The authors [29] noted that a cogeneration system consisting of a hybrid photovoltaic system connected to the distribution network, a diesel generator, and batteries becomes a viable alternative for significant energy-consuming centers, like a hospital, based on the results of the simulation scenarios analyzed with HOMER software. It makes sense for this system to reduce greenhouse gas emissions from the atmosphere while still meeting load demand.

The authors [29] pointed out that the optimization of designed hybrid renewable energy systems can consist of optimization problems with multiple objectives, such as environmental management, control, or optimization system, as well as single-objective optimization problems, such as optimizing the size of system elements to minimize overall costs.

Researchers in [30], [31] looked into the drawbacks of putting a hybrid system into place. In order to use hybrid systems, optimization problems involving one or more objectives must be solved. Examples of these problems include sizing the system to minimize energy costs, controlling the system to balance the uncertainty of the energy produced, and lowering greenhouse gas emissions. All of these problems are based on multi-objective optimization techniques. They discovered that the most frequently utilized objective functions in the optimization of multiple objectives of hybrid renewable energy systems are system cost minimization and system reliability maximization. This is based on optimization theory, which is concerned with the mathematical study of problem-solving for minimum or maximum values of an objective function.

Hybrid PV - EES Systems: Optimization Methods And Algorithms

Several noisy nonlinear mathematical optimization issues in engineering and design cannot be solved efficiently with traditional optimization methods. However, metaheuristic algorithms like Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) have gained a lot of popularity since they appear to be quite effective at tackling these issues.

Two well-known heuristic algorithms, Genetic Algorithm (GA) and Particle Swarm (PSO), were compared in [32] with other, more recent metaheuristic algorithms, which are used to find optimal solutions to noisy non-linear optimization problems. These algorithms include the Gray Wolf Optimizer (GWO) algorithm, Firefly Algorithm (FA), and Brain Storm Optimization (BSO). In the majority of test instances, GA and PSO fared really well, according to the authors. However, GWO also showed that it is a highly competitive algorithm capable of solving noisy non-linear optimization problems in terms of both runtime and precision. At runtime, FA is also a rather competitive algorithm. In contrast, FA's accuracy data indicated that several test functions yielded subpar results. Ultimately, BSO is an algorithm whose precision is acceptable but whose runtime is ineffective.

In [33], an enhanced heuristic classification is offered as a foundation for future studies to operate equitably heuristically. In order to identify distinctive characteristics that can aid in differentiating each heuristic among them, the study team created a thorough diagnosis of heuristic categorization schemes. They stress that having a thorough understanding of a heuristic's properties and search behavior is essential before putting it into practice.

The sizing procedures for hybrid renewable energy systems (independent and connected to the grid) were primarily examined in [34]. These methodologies are based on a combination of traditional, artificial intelligence, hybrid, and computational technologies.

In order to talk about operating strategy optimization for hybrid systems, we refer to [35,36,37,38,39,40,41,42, 43].The writers emphasized both traditional and cutting-edge optimization techniques applied to microgrid applications. They suggested that by employing these methodologies, various control optimization strategies may be put into practice to enhance the performance and integration of renewable energy sources into microgrids. As a result, numerous researchers have developed artificial intelligence, which has made it possible to optimize microgrid control and guarantee clients a sustainable supply of electricity.

To locate and size the distributed generation in a distribution system, the authors of [44] compared the metaheuristic approaches Tabu Search (TS), Scatter Search (SS), and Ant Colony (AC). The suggested approach was evaluated in IEEE systems with 13 nodes, comparing the results of the SS, TS, and AC algorithms. emphasizing that, in terms of solution correctness and convergence process, SS was superior to TS and AC.

Conclusion

The state of the art for hybrid systems that use unconventional renewable energy sources in sanitary installations is reviewed in this paper. The primary tasks, methods, and metrics for completing electricity consumption profiles and assessing energy efficiency in sanitary facilities have been determined. This has made it possible for us to pinpoint the various algorithms and optimization strategies based on heuristic and mathematical methods that are applied to hybrid electrical systems, thereby resolving issues with sizing, operating strategy, and energy management.

References

1. Vaziri, Rezaee, & Monirian, ”Utilizing renewable energy sources effi- ciently in hospitals using demand dispatch”,in Renewable Energy, 2019.
2. Nils Christiansen *et. al*, “Electrical energy consumption and utilization time analysis of hospital departments and large scale medical equipment”, Energy and Buildings, Volume 131, 2016.
3. C. Shen, K. Zhao, J. Ge, and Q. Zhou, “Analysis of building energy consumption in a hospital in the hot summer and cold winter area,” in Energy Procedia, 2019, vol. 158, pp. 3735–3740.

4. A. G. Gonza´lez, J. Garc´ıa-Sanz-Calcedo, and D. R. Salgado, “Evaluation of energy consumption in German hospitals: Benchmarking in the public sector,” Energies, vol. 11, no. 9, Sep. 2018.
5. Yi Wang *et. al*, “Load profiling and its application to demand response: A review,” Tsinghua Sci. Technol., vol. 20, no. 2, pp. 117–129, Mar. 2016.
6. J. Garc´ıa-Sanz-Calcedo, M. Go´mez-Chaparro, and G. Sanchez-Barroso, “Electrical and thermal energy in private hospitals: Consumption indica- tors focused on healthcare activity,” Sustain. Cities Soc., 2019.
7. Arocas Sergio M., Coria Hoffmann Geraldine D. y Bosc Cristian, “Identificacio´n de indicadores energe´ticos para el disen˜o de un programa de ahorro y eficiencia energe´tica en una Instalacio´n Hospitalaria”, Facultad de Ingenier´ıa UNLP,2019.
8. A. Gonza´lez Gonza´lez, J. Garc´ıa-Sanz-Calcedo, and D. R. Salgado, “A quantitative analysis of final energy consumption in hospitals in Spain,” Sustain. Cities Soc., vol. 36, pp. 169–175, Jan. 2018.
9. T. Wang, X. Li, P. C. Liao, and D. Fang, “Building energy efficiency for public hospitals and healthcare facilities in China: Barriers and drivers,” Energy, vol. 103, pp. 588–597, May 2016.
10. K. Bawaneh, F. Ghazi Nezami, M. Rasheduzzaman, and B. Deken, “En- ergy Consumption Analysis and Characterization of Healthcare Facilities in the United States,” Energies, vol. 12, no. 19, p. 3775, Oct. 2019.
11. Hwang, Cho, and Moon, “Feasibility Study on Energy Audit and Data Driven Analysis Procedure for Building Energy Efficiency: Bench- Marking in Korean Hospital Buildings,” Energies, vol. 12, no. 15, p. 3006, Aug. 2019.
12. A. Prudenzi, A. Fioravanti, and V. Caracciolo, “Resilient power in hospitals: The S. Giovanni addolorata general hospital case study,” in 2017 AEIT International Annual Conference: Infrastructures for Energy and ICT: Opportunities for Fostering Innovation, AEIT 2017, 2017, vol. 2017-January, pp. 1–6. Energy and ICT: Opportunities For Fostering Innovation ,AEIT 2017,2017,vol.2017-January,pp.1-6.
13. B. N. Lobov, P. G. Kolpakhch’yan, S. A. Belokopytov, and A. D. R. Ali Madzhid, “A choice of the structure of the photovoltaic system for power supply,” Russ. Electr. Eng., vol. 86, no. 7, pp. 398–402, Jul. 2015.
14. Giovanni Petrone, Carlos Andres Ramos-Paja, Giovanni Spagnuolo. Photovoltaic Sources Modeling, Wiley-IEEE Press, 2017.
15. N.D. Kaushika , Anuradha Mishra & Anil K. Rai, Solar Photovoltaics, Springer International Publishing,2018.

16. Weidong Xiao,Photovoltaic Power System: Modeling, Design, and Control,Wiley,2017.
17. Bo Zhao, Caisheng Wang, Xuesong Zhang,Grid-Integrated and Stan- dalone Photovoltaic Distributed Generation Systems: Analysis, Design, and Control,Wiley,2017.
18. C. Ghenai and M. Bettayeb, "Modelling and performance analysis of a stand-alone hybrid solar PV/Fuel Cell/Diesel Generator power system for university building," Energy, vol. 171, pp. 180–189, Mar. 2019.
19. M. Jariso, B. Khan, D. Tesfaye, and J. Singh, "Modeling and designing of stand-alone photovoltaic system: CaseStudy: Addis Boder health center south west Ethiopia," in Proceedings of the International Conference on Electronics, Communication and Aerospace Technology, ICECA 2017, 2017, vol. 2017-January, pp. 168–173.
20. A. Bouraiou, M. Hamouda, A. Chaker, M. Sadok, M. Mostefaoui, andS. Lachtar, "Modeling and Simulation of Photovoltaic Module and Array Based on One and Two Diode Model Using Matlab/Simulink," in Energy Procedia, 2015, vol. 74, pp. 864–877.
21. J. Liu, X. Chen, S. Cao, and H. Yang, "Overview on hybrid solar photovoltaic-electrical energy storage technologies for power supply to buildings," Energy Conversion and Management, vol. 187. Elsevier Ltd,pp. 103–121, 01-May-2019.
22. A. H. Fathima and K. Palanisamy, "Optimization in microgrids with hybrid energy systems - A review," Renewable and Sustainable Energy Reviews, vol. 45. Elsevier Ltd, pp. 431–446, 01-May-2015.
23. A. L. Bukar and C. W. Tan, "A review on stand-alone photovoltaic- wind energy system with fuel cell: System optimization and energymanagement strategy," Journal of Cleaner Production, vol. 221. Elsevier Ltd, pp. 73–88, 01-Jun-2019.
24. M. Hijjo, F. Felgner, and G. Frey, "PV-Battery-Diesel microgrid layout design based on stochastic optimization," in 2017 6th International Conference on Clean Electrical Power: Renewable Energy Resources Impact, ICCEP 2017, 2017, pp. 30–35.
25. A. Bosisio, M. Moncecchi, G. Cassetti, and M. Merlo, "Microgrid design and operation for sensible loads: Lacor hospital case study in Uganda,"Sustain. Energy Technol. Assessments, vol. 36, p. 100535, Dec. 2019
26. S. V. Cotto and W. J. Lee, "Microgrid modular design for Tribal Healthcare facilities: Kayenta Health Center used as guidance for concept model for

Navajo Nation," in 2017 IEEE Industry Applications Society Annual Meeting, IAS 2017, 2017, vol. 2017-Janua, pp. 1–8.

27. R. Dufo-Lo´pez, E. Pe´rez-Cebollada, J. L. Bernal-Agust´ın, and I. Mart´ınez-Ruiz, "Optimisation of energy supply at off-grid healthcare facilities using Monte Carlo simulation," Energy Convers. Manag., vol. 113, pp. 321–330, Apr. 2016.
28. L. Olatomiwa, "Optimal configuration assessments of hybrid renewable power supply for rural healthcare facilities," Energy Reports, vol. 2, pp. 141–146, nov. 2016
29. N. M. Isa, H. S. Das, C. W. Tan, A. H. M. Yatim, and K. Y. Lau,
30. "A techno-economic assessment of a combined heat and power photo-voltaic/fuel cell/battery energy system in Malaysia hospital," Energy, vol. 112, pp. 75–90, Oct. 2016
31. Tuba Tezer, Ramazan Yaman, Gu¨ls¸en Yaman, Evaluation of approaches used for optimization of stand-alone hybrid renewable energy systems, Renewable and Sustainable Energy Reviews, Volume 73,2017,Pages 840-853.
32. Jijian Lian, Yusheng Zhang, Chao Ma, Yang Yang, Evance Chaima, A review on recent sizing methodologies of hybrid renewable energy systems, Energy Conversion and Management, Volume 199,2019.
33. V. Sai et al., "Comparative Study on Recent Development of Heuristic Optimization Methods," 2016 Third International Conference on Comput- ing Measurement Control and Sensor Network (CMCSN), Matsue, 2016,
34. pp. 68-71.
35. E. M. Nazri and S. Murairwa, "Classification of heuristic techniques for performance comparisons," 2016 12th International Conference on Mathematics, Statistics, and Their Applications (ICMSA), Banda Aceh, 2016, pp. 19-24.
36. Samir M. Dawoud, Xiangning Lin, Merfat I. Okba, Hybrid renewable microgrid optimization techniques: A review, Renewable and Sustainable Energy Reviews,Volume 82, Part 3, 2018,Pages 2039-2052.
37. S. Leonori, M. Paschero, F. M. Frattale Mascioli, and A. Rizzi, "Opti- mization strategies for Microgrid energy management systems by Genetic Algorithms," Appl. Soft Comput. J., vol. 86, p. 105903, Jan. 2020.
38. C. Gamarra and J. M. Guerrero, "Computational optimization techniques applied to microgrids planning: A review," Renewable and Sustainable Energy Reviews, vol. 48. Elsevier Ltd, pp. 413–424, 01-Aug-2015.

39. Jp. Clean, “Optimised controller for renewable energy sources integration into microgrid: Functions, constraints and suggestions,”, Feb. 2020.

40. Zack Stokes, Abhyuday Mandal, Weng Kee Wong,Using Differential Evolution to design optimal experiments,Chemometrics and Intelligent Laboratory Systems,Volume 199,2020.

41. J. Jobanputra and C. Kotwal, ”Optimal Power Dispatch using Particle Swarm Optimization,” 2018 International Conference on Smart Electric Drives and Power System (ICSEDPS), Nagpur, 2018, pp. 157-161.

42. T. M. Mohan and T. Nireekshana, ”A Genetic Algorithm for Solving Optimal Power Flow Problem,” 2019 3rd International conference on Electronics, Communication and Aerospace Technology (ICECA), Coim- batore, India, 2019, pp. 1438-1440.

43. Sara Ghaem Sigarchian, Matthew S. Orosz, Harry F. Hemond, Anders Malmquist, Optimum design of a hybrid PV–CSP–LPG microgrid with Particle Swarm Optimization technique, Applied Thermal Engineer- ing,Volume 109, Part B,2016,Pages 1031-1036.

44. Maher Azaza, Fredrik Wallin, Multi objective particle swarm optimization of hybrid micro-grid system: A case study in Sweden, Energy, Volume 123, 2017,Pages 108-118.

45. Juan Uparela , Samuel Hernandez, Ingrid Oliveros, Jose Soto Ortiz, Elvin Jimenez, Leandro Zurek,.“Sistema Fotovoltaico no interconectado: caso Providencia”. 10.18687/LACCEI2018.1.1.166.(2018).

46. Luis Lo´pez D´ıaz , Jose Doria-Garcia, Carlos Pimienta, Adriana Arango-Manrique.“Distributed Generation Allocation and Sizing: A Compari- son of Metaheuristics Techniques”. 1-6. 10.1109/EEEIC.2019.8783934. (2019)..

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8

An Overview of Smart Grid Technology and Its Features

Suryendu Dasgupta*
Department of Electrical Engineering, Swami Vivekananda University, Kolkata, West Bengal

***Corresponding Author:** suryendu.skfgi@gmail.com

Abstract

When it comes to utilizing the smartest technology available, everyone is aware that a straightforward yet efficient system may be used to generate and distribute power across the nation. Smart Grid technology is able to offer this special function. Numerous aspects allow for differentiating the Smart Grid in numerous ways from the current traditional grid. The Smart Grid (SG) technology was essentially the main topic of this paper. A technology that has enabled us to imagine solutions for challenges involving maximum power, from generation to distribution ends. In this era of rapid technological development, where governments are struggling to meet consumer demand for electricity, smart grids can balance the supply and demand for electricity. A brief overview of smart grid technology and its applications has been covered in this paper.

Introduction

The days are transforming. Additionally, civilization is developing considerably more. Science is growing stronger as time goes by. In the contemporary world, scientists and engineers encounter difficulties in meeting consumer demands at varying levels for a variety of reasons. The entire power generating and distribution system is a loss project due to a lack of supply, corruption at both the sending and receiving ends, transmission and distribution losses, and other issues. Because of this, the concept of smart grid technology has been established in order to meet demand, improve the efficiency of the power generation and distribution system, increase consumer security, and monitor and control the entire system via two-way communication (generating end and receiving end). Therefore, becoming familiar with smart grids and smart applications is the paper's core focus.

A smart grid is a concept that unifies the whole electricity distribution and generation system into one unit. To put it another way, a smart grid is one that makes the entire system cleaner and smarter. Nowadays, demand for clean energy exists everywhere in the world. Thus, clean energy is smart energy. The first instance of the term "smart gird" was used in 2003. At that point, the phrase was first used in an article by Michael T. Burr [I]. There he elucidated the process of identifying and eliminating the power grid's shortcomings in order to improve the power flow system from the generation end to the distribution end via the transmission network as a whole. This idea of a "smart grid" is now becoming a reality with the excellence of performing some unique feature which is making things easier (the comprehension of supplier and consumer behavior as well as safety). The protection system of the grid, central control via the Supervisory Control and Data Acquisition (SCADA) system, diagnostic monitoring of all transmission equipment, treating the entire power system as a complex adaptive power system, Grid Computing, and utilizing distributed computer agents to make the power system a self-healing network are all methods that contribute to the creation of a smart grid.

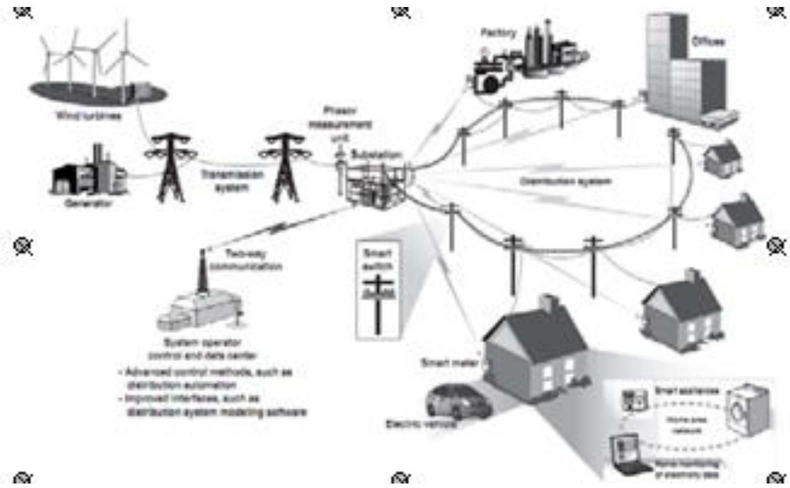

Fig.1: Representation of Smart Grid Technology [12]

The essence of the traditional, existing, or conventional power system is sluggish. Customers' privacy is not provided by it. It was unable to create a network that could be used for communication between customers and electricity providers. We were unable to obtain real-time data on supply and consumption at any given point in the generation and distribution system at any given moment from the traditional electricity grid.

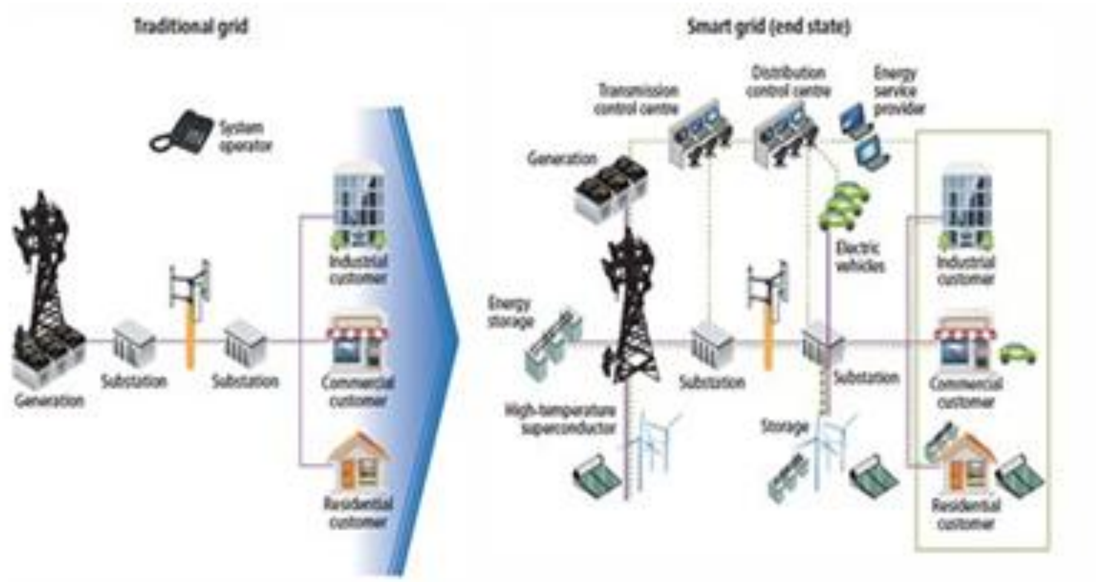

Fig. 2: A Representation of Difference between Smart Grid and Traditional Grid

Lack of accuracy in the electricity usage measurement system made the entire system susceptible to electricity theft. In the traditional grid, it was simple to steal electricity from the national grid from any point in the system without the authority of the electricity supply, which resulted in losses that were unavoidable and insufficient generation to meet consumer demand. Another problem with the existing grid was a lack of safety. Since there aren't many safety devices in the current grid, it can be difficult to identify and minimize system faults. Additionally, if a problem arises with the current grid, the entire region may go dark until the issue is identified and resolved. Regarding the current grid, there are numerous other issues.

The goal of smart grid is to address nearly every query pertaining to issues that crop up in the current grid. Both the supplier's and the user's end of the system can be monitored by Smart Grid. A customer can precisely determine how much electricity he uses from his residence, and the supplier can keep track of how much electricity each customer uses. In this sense, the idea of smart metering is having revolutionary effects. The safety features offered by smart grid are able to shield the system from any type of vulnerable damage. The Smart Grid's ability to identify faults and repair itself is making it an indispensable component of the contemporary environment.

There are further ways to distinguish between the current grid and the intelligent grid, or smart grid. Whereas the Smart Grid is digital (computerized control), the current grid is electromechanical. There is an obvious distinction between the two communication systems (one way and two way). The current grid was created using a hierarchical architecture. Smart Grid, however, is a fully network-based solution. The current grid offers very few options for customers. However, customer preferences were given precedence in the smart grid. As a result, users of the Smart Grid system have numerous options [2].

Smart Grid Features

The smart grid is becoming so intelligent that it is imperative to comprehend its features in order to guarantee optimal utilization of the technology. The following is a description of the characteristics of Smart Grid technology:

Bidirectional Communication System (BCS), Smart Meters (SM), Distributed Generations (DG), Renewable Energy Integrations (REI), and

- The ability to heal automatically (AHC)
- Cybersecurity and Data Protection
- CarbonEmission Reduction Field Area Networks (FAN)
- Meter Data Management (MDM)

Demand response, energy storage devices, distribution automation, IT and back office computing.

These are the general characteristics of smart grid technology. The Smart Grid technology has other features. Only a few of them are described in detail here.

- **Smart Meters**

The Smart Meter is a special characteristic of the Smart Grid technology that makes it the most accurate data-measuring tool for electricity generation and consumption. Smart metering is the practice of integrating sophisticated meters with communication networks to give users real-time monitoring of their energy use [3]. Put simply, a smart metre is a device that measures the amount of electricity that users use. It typically takes the reading a few times a day and after a specific time.

Fig. 3: Smart Meter

A typical smart meter assists customers in controlling their electricity usage in accordance with their specified billing limit or budget by educating them about billing procedures and electricity usage. On the other hand, smart meter measurement aids providers in creating accurate invoices for customers utilizing grid electricity.

- **Distributed Generations**

A key component of smart grid technology is distributed generation (DG). Distributed generation is the process of producing power from tiny energy sources. Large-scale power plant generating has a fairly secure supply of electricity through the grid, but it also has certain negative effects on distribution and transmission in the environment [4]. In the case of a smart grid, distributed generation is more useful and presents challenges for provider authorities. The following are some difficulties that providers may encounter:

  - Electricity demand responding to market forces. It entails comprehending consumer demand for electricity and creating a user-oriented marketplace to guarantee ideal demand response.
  - Ensuring the stability of distributed generation and the flow of power from the point of generating to the point of distribution.
  - Ensuring cost-effective production and distribution processes so that costs don't go above the consumers' intended limit
  - Environmental safety is a crucial factor in safeguarding the Grid against many types of natural calamities.

- **Renewable Energy Integration (REI)**

The Smart Grid's incorporation of renewable energy is another crucial component. Improving the grid's capacity for REI (Renewable Energy Integration) enables the national system to potentially securely satisfy consumers' extended demands. Similar to distributed generation (DG), integration of REI with the smart grid (SG) presents some obstacles.

One of the most important considerations when it comes to the generation and integration of renewable energy is the environmental impact. If solar energy is unavailable at night, the integration system must take the appropriate measures to make up for the loss of solar energy. One such measure is to install a solar electricity storage system so that the grid may receive solar electricity throughout the night. One of the main obstacles to incorporating renewable energy sources into the grid is voltage fluctuation. It specifically occurs during the grid's integration of solar and wind energy sources. Inconsistent solar radiation and variable wind speeds are the causes of these sources' voltage fluctuations [5].

The integration of renewable energy sources into the system presents numerous additional obstacles.

- **Bidirectional Communication System (BCS)**

It is simpler for suppliers and customers to employ Smart Grid technology when the bi-directional communication system is enabled. Interacting with the smart grid is similar to having a phone conversation in that both parties are aware of the clear billing of the electricity usage and generation, as well as the pricing and utilization of the energy. Furthermore, only this communication mechanism allows for central Grid monitoring. One thing, though, needs to be kept in mind: whether bidirectional or multidirectional communication occurs in the grid, privacy needs to be protected.

- **Automatic Healing Capability**

Automatic Healing Capability (AHC) is a feature that must be included in Smart Grid (SG) technology, which is a smart system for producing power and distributing it to users with a strong confirmation of data security, robustness, and ease. This feature includes the capacity for the system to automatically identify abnormal situations like as overcurrent, surge voltage, fault current, etc.; it also sends the information to the central control room and has the capability to automatically recover or heal faults or disturbances that have occurred.

- **Data Security or Cyber Security**

Technology used in smart grids needs to be protected against serious threats and attacks. Hackers, cyberterrorists, organized crime, certain criminal elements, industrial rivals, and negligent or ill-trained staff are some of the potential threats to the smart grid. To take advantage of holes in the system, a group of hackers, cyberterrorists, lone criminals, or organized crime can target smart grid networks and systems. When untrained staff operate the system carelessly, the entire system becomes open to security breaches. Because the technology is integrated throughout the entire system, an attack on one area of the network might eventually expose the entire system to considerable risk and perhaps result in a complete blackout or system failure. For this reason, the system's cyber security needs to be robust enough to ensure smooth operation.

- **Carbon Emission Reduction**

Green Grid is Smart Grid. Clean energy is smart energy. Because smart grid technology allows for the integration of renewable energy sources into the system as well as efficient energy generation and distribution, carbon emissions are reduced by a significant amount.

Smarter Grid: Smarter Policies

Since the Smart Grid unifies the digitization, cleanliness, and security of the electricity generation and transmission system under one roof, some rules are necessary to improve the overall efficiency of the system. Diverse nations are developing various policies aimed at improving the intelligence of the grid.

The Department of Energy in the United States reports that in 2009, a few pilot projects were chosen to showcase various distributed system integration smart grid technologies, with the main objective being a fifteen percent reduction in peak demands. These projects were spread over several US states, including West Virginia, Illinois, and New York [6].

Seventy-five standards, covering a wide range of subjects like internet, telecommunication, and the power industry, were selected by NIST in their Framework and Roadmap for Smart Grid Interoperability Standards, Release 1.0, which was released in January 2010. NIST established a Smart Grid Interoperability Panel of 22 parties, which has been contributing to the development of regulations [7].To make the smart grid system more intelligent and practical for both the controlling body and the consumers, policies similar to the ones mentioned above have been implemented.

Benefits of Smart Grid

The use of smart grid technology has many advantages. Large-scale lifesaving; lowering utility bills; increasing the economy and job market; providing more dependable services through fewer and shorter outages; and substituting cleaner renewable energy for dirtier fossil fuels.

Impacts of Geographical Location

While the fundamental ideas behind smart grid technologies are virtually the same nationwide, the primary focus varies based on the country's physical location. Research has demonstrated that operational procedures and control policies vary from nation to nation and area to area. For example, the United States is a more advanced user of smart grid technology. They give users and service integration a lot of attention. However, China is less immature in this regard and places a lot of emphasis on bulk electricity transmission [8].

Smart Grid Vision: Technological Roadmap

A clear plan is always necessary to ensure that the process proceeds smoothly and impartially. A variety of roadmaps have been established by many nations to increase the intelligence of the upcoming generation. China's roadmap accounts for the growth in demand over the next 20 years in terms of percentages for the Smart Grid's Maximum and Minimum values. These percentages have been anticipated to be 56, 99, 140, and 200 percent for the Smart Grid Minimum and 55, 9 1, 125, 176 percent for the Smart Grid Maximum in 2020, 2030, 2040, and 2050. North America, the European Union, the Pacific, and China have all set goals [9].

Brazil's hydroelectricity integrated network is demonstrating improved performance in raising the distributed system's efficiency. Two 600KV HVDC converter stations with a combined capacity of 3,175 MW of power have been developed in order to deliver this generated hydroelectricity from the sea area to the main cities in Brazil [10].

Conclusion

The implementation of Smart Grid technology is important for all countries to meet the increasing demand for electricity. The time will come when every nation on the planet is linked into a worldwide network to improve the intelligence and cleanliness of their electrical systems. Therefore, a set of standard policies for the globally interconnected networked smart grid technologies must be created.

References

1. Michael T. Burr. "Reliability demands will drive automation investments."Internet: www.fortnightly.comlfortnightly/2003/II/technology-corridor. Nov 1, 2003 [Aug. 05, 2013].
2. Farhangi, H. "The path of the smart grid". IEEE Power and Energy Magazine, Vol-8, Issue-I,PP-20,Jan/Feb. 2010.
3. Wipro Technologies."Achieving Sustainability Through Smart GridSmart Meter. "Internet:www.wipro.comiDocuments/Achieving_Sustainability_Through
4. _Smart_Meter_Smart_Grid.pdf, PP-03 [Aug. 02,2013]
5. www.wikipedia.org
6. GM Shafiullah,Amanullah M. T. 00, Dennis Jarvis, ABM Shawkat Ali, Peter Wolfs -"Potential Challenges: Integrating Renewable Energy with the Smart Grid"-Universities Power Engineering Conference (AUPEC), 2010 20th Australasian
7. Department of Energy. Enhancing the smart grid: Integrating clean distributed and renewable generation. Washington, DC: Office of Electricity Delivery and Energy Reliability. [2009]
8. "Smart Grid Interoperability Standards". NIST
9. M. Hashmi, Member, IEEE, S. Hanninen, and K. Maki-"Survey of Smart Grid Concepts, Architectures, and Technological Demonstrations Worldwide"- IEEE PES Conference onInnovative Smart Grid Technologies (ISGT Latin America), 2011
10. Technology Roadmap, Smart Grid, IEA,20II
11. ALSTOM
12. S Massoud Amin and Bruce F. Wallenberg, Toward a Smart Grid- IEEE power and Energy Magazine, September/October 2005
13. www.news.cnet.com
14. www.iea.org.

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9 Applications of Sliding Mode Control in Engineering Systems

Tanmay Sinha Roy*
Department of Electronics and Communication Engineering, Swami Vivekananda University, Barrackpore, West Bengal, India

***Corresponding Author:** tanmoysinha.roy@gmail.com

Abstract

Sliding Mode Control (SMC) has gained substantial attention due to its robustness and simplicity in handling nonlinear systems with uncertainties. Its unique approach involves driving the system state trajectories onto a predefined sliding surface and maintaining motion on that surface. This paper presents an overview of the principles of SMC, followed by a comprehensive discussion of its applications in various engineering fields such as robotics, automotive systems, power electronics, aerospace, and renewable energy systems. The focus is on the advantages and challenges associated with the implementation of SMC in real-world applications, as well as ongoing research trends.

Introduction

Sliding Mode Control (SMC) is a robust control strategy that is widely used in controlling systems that are nonlinear, have model uncertainties, or are subject to external disturbances. The technique involves switching control to drive the system to a desired trajectory and maintain it on that path despite uncertainties. This switching action offers robustness to parameter variations, making SMC suitable for a range of challenging applications.

Basic Principles of Sliding Mode Control

Sliding Mode Control operates by enforcing a sliding condition on the system, which forces the state trajectories to remain on a sliding surface, ensuring stability. The design involves:

- **Sliding Surface Design**: The system's behavior is controlled by designing an appropriate sliding surface.
- **Reaching Phase**: This phase brings the system state to the sliding surface.
- **Sliding Phase**: Once the state is on the surface, it remains there.

The control law is usually discontinuous, which can lead to a phenomenon known as "chattering." Strategies such as higher-order sliding modes and smoothing techniques have been developed to reduce or eliminate this effect.

Applications of Sliding Mode Control

- **Robotics**

SMC has been extensively applied in robotic systems, particularly for trajectory tracking, motion control, and force control. Robotic manipulators, often dealing with nonlinear dynamics and unknown payloads, benefit from SMC's robustness. SMC is used for **trajectory tracking** in multi-link robotic arms, where it ensures precise tracking under uncertain dynamics and external disturbances.

- **Automotive Systems**

In the automotive industry, SMC has been applied in various areas such as **anti-lock braking systems (ABS)**, **traction control**, and **engine control**. For instance, in ABS, SMC provides a robust solution by reducing the uncertainties related to tire-road friction and enhancing braking efficiency. Moreover, in **vehicle dynamics control**, SMC has been employed to maintain vehicle stability in conditions like sudden steering or rough terrain.

- **Power Electronics**

Sliding Mode Control is highly effective in power electronics, particularly in **DC-DC converters** and **inverters**. The highly nonlinear behavior of power electronic circuits, along with fast-switching dynamics, makes them ideal candidates for SMC. For instance, in DC-DC converters, SMC is used to regulate output voltage under varying load conditions and input fluctuations.

- **Aerospace**

In the aerospace field, SMC is used for **attitude control** of spacecraft and aircraft due to its robustness against modeling inaccuracies and external disturbances like wind gusts. The use of SMC in **flight control systems** provides superior performance in terms of maintaining stability and trajectory in the presence of uncertainties.

- **Renewable Energy Systems**

The increasing use of renewable energy systems such as **wind turbines** and **solar photovoltaic systems** has led to the adoption of SMC for improved performance. For wind turbines, SMC ensures optimal power extraction by controlling the pitch of the blades, even under varying wind conditions. Similarly, in solar PV systems, SMC is used for **maximum power point tracking (MPPT)**, ensuring efficient energy conversion despite changes in sunlight intensity.

Challenges and Limitations

Despite its advantages, Sliding Mode Control is not without its challenges:

- **Chattering**: The high-frequency switching action inherent in SMC can lead to chattering, which may cause wear and tear in mechanical systems or undesirable oscillations in electrical systems.
- **Model Accuracy**: The design of the sliding surface requires an accurate model of the system, which may not always be available or easy to obtain.
- **Complexity in Higher-Order Systems**: In some cases, implementing higher-order SMC can become complex and computationally intensive, especially in systems with multiple inputs and outputs.

Recent Trends and Future Directions

Ongoing research in SMC is focused on overcoming its limitations and expanding its applications. Current trends include:

- **Higher-Order Sliding Modes**: To reduce chattering while maintaining robustness, higher-order SMC techniques are being developed and applied to complex systems.
- **Adaptive Sliding Mode Control**: Adaptive control methods are being combined with SMC to handle greater uncertainties and improve performance in systems with time-varying dynamics.
- **Distributed Control Systems**: SMC is being integrated into distributed control architectures, such as networked control systems and multi-agent systems, to enhance robustness in decentralized applications.

Conclusion

Sliding Mode Control continues to be a powerful tool in controlling nonlinear systems with uncertainties. Its applications span a wide range of fields, from robotics to aerospace, demonstrating its versatility and robustness. While challenges like chattering persist, ongoing research is providing solutions that improve the practicality and efficiency of SMC in modern engineering systems.

References

1. Bartolini, G., Ferrara, A., & Usai, E. (1998).Chattering Avoidance by Second-Order Sliding Mode Control. *IEEE Transactions on Automatic Control, 43*(2), 241-246.
2. Defoort, M., Shtessel, Y., Floquet, T., & Edwards, C. (2010). Sliding Mode Control of Nonlinear Systems Using Observer-Based Output Feedback: Application to Induction Motors. *International Journal of Control, 83*(8), 1677-1690.
3. Emelyanov, S. V., Korovin, S. K., & Levant, A. (1996). High-Order Sliding Modes in Control Systems. *Computational Mathematics and Modeling, 7*(3), 294-318.
4. Floquet, T., Barbot, J. P., & Perruquetti, W. (2007).Higher Order Sliding Mode Stabilization for a Class of Nonlinear Systems.*Automatica, 43*(5), 907-914.
5. Levant, A. (2003).Higher-Order Sliding Modes, Differentiation and Output-Feedback Control.*International Journal of Control, 76*(9-10), 924-941.
6. Shtessel, Y., Edwards, C., Fridman, L., & Levant, A. (2014). *Sliding Mode Control and Observation*. Birkhäuser.
7. Slotine, J. J. E., & Li, W. (1991). *Applied Nonlinear Control*. Prentice Hall.
8. Sira-Ramírez, H., & Spurgeon, S. K. (2004).Application of Sliding Mode Control to Electric Power Systems.*IEEE Transactions on Control Systems Technology, 12*(6), 877-888.
9. Utkin, V. I. (1992). *Sliding Modes in Control and Optimization*. Springer.
10. Zavala-Río, A., & Aguilar, L. T. (2007).Output Tracking of Robot Manipulators Using Higher Order Sliding Modes. *IEEE Transactions on Control Systems Technology, 15*(4), 852-858.

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10

Semantic Analysis and Knowledge Extraction for Optimizing Sustainable Resource Management

Arijit Mukherjee*

Department of Mechanical Engineering,Swami Vivekananda University, Kolkata, West Bengal

***Corresponding Author:** arijitm@svu.ac.in

Abstract

As global challenges around resource depletion, climate change, and sustainability intensify, effective management of natural resources has become critical. Semantic analysis and knowledge extraction techniques, which are part of Natural Language Processing (NLP), offer powerful solutions for handling vast amounts of data related to resource management. These methods can uncover valuable insights, patterns, and trends from unstructured data, such as reports, regulatory documents, and research publications, which support better decision-making for sustainable resource management. This review explores how semantic analysis and knowledge extraction are applied in sustainable resource management. It highlights the methodologies, applications, challenges, and potential future opportunities in leveraging these technologies to enhance the efficient use of natural resources and promote environmental sustainability.

Introduction

Sustainable resource management involves the careful use and conservation of natural resources, such as water, energy, and land, to meet current demands while preserving these resources for future generations. The increasing pressure on global resources due to population growth, industrialization, and environmental degradation has created an urgent need for better resource management strategies. However, managing these resources effectively requires an in-depth understanding of the complex systems that govern their use and availability.

Semantic analysis and knowledge extraction, techniques from the field of NLP, offer new ways of analyzing and organizing large amounts of data relevant to sustainable resource management. These techniques facilitate the extraction of structured information from unstructured data, making it possible to derive insights from documents, reports, and other textual resources. This paper reviews the role of semantic analysis and knowledge extraction in sustainable resource management, focusing on how these tools support decision-making and resource optimization.

Semantic Analysis and Knowledge Extraction: An Overview

- **Defining Semantic Analysis**

Semantic analysis is the process of interpreting and understanding the meaning of words, phrases, and sentences in a given context. It aims to identify the relationships between different concepts in a text, such as identifying synonyms, antonyms, and hierarchical relationships between terms. Semantic analysis goes beyond simple keyword matching to understand the contextual meaning of terms and extract deeper insights from text (Cambria & White, 2014).

- **Knowledge Extraction in NLP**

Knowledge extraction involves identifying and organizing relevant information from unstructured data sources. In the context of sustainable resource management, knowledge extraction allows for the identification of key facts, concepts, and relationships related to resource use, environmental impact, and management strategies. This information can then be used to build knowledge bases, support decision-making processes, and enhance understanding of complex systems (Hogenboom et al., 2015).

Together, semantic analysis and knowledge extraction enable the processing of large volumes of unstructured data to derive meaningful insights that can inform sustainable resource management strategies.

Applications of Semantic Analysis and Knowledge Extraction in Sustainable Resource Management

- **Water Resource Management**

One of the critical applications of semantic analysis and knowledge extraction is in water resource management. Effective water management involves balancing the needs of agriculture, industry, and communities while ensuring the sustainability of water sources. Semantic analysis can be used to analyze policy documents, research publications, and environmental reports to identify water usage patterns, legal regulations, and emerging threats to water security (Lele et al., 2018).

By extracting relevant knowledge from unstructured data sources, such as government reports and scientific studies, semantic analysis tools can help identify trends in water availability, predict future demand, and support policy development aimed at conserving water resources.

- **Sustainable Energy Management**

Renewable energy sources, such as solar, wind, and hydropower, are crucial for achieving sustainability goals. However, managing energy resources efficiently requires continuous monitoring of energy production, consumption patterns, and environmental impacts. Semantic analysis enables the extraction of insights from various energy-related data sources, including energy policy reports, market analyses, and technology reviews (Cao et al., 2021).

For example, semantic analysis tools can identify trends in energy consumption, pinpoint regions with high renewable energy potential, and assess the environmental benefits of transitioning from fossil fuels to renewables. This knowledge supports decision-makers in optimizing energy production and distribution to minimize environmental impact while meeting energy demands.

- **Climate Change Adaptation and Land Management**

Land management strategies that promote sustainable agriculture and biodiversity conservation are essential for mitigating the effects of climate change. Semantic analysis of environmental data can help extract valuable insights related to land use patterns, deforestation rates, soil health, and climate impacts. Knowledge extraction from climate reports, satellite imagery, and scientific literature can provide a detailed understanding of how land use is evolving and the best practices for managing ecosystems sustainably (Cowie et al., 2019).

In addition, semantic analysis can uncover the relationships between land use policies, climate adaptation strategies, and agricultural productivity, offering a comprehensive view of how sustainable land management practices can contribute to both climate resilience and food security.

Benefits of Semantic Analysis and Knowledge Extraction for Sustainable Resource Management

- **Enhanced Decision Support**

One of the main benefits of using semantic analysis and knowledge extraction in resource management is improved decision support. By processing large datasets from diverse sources, these tools provide decision-makers with comprehensive insights that would be impossible to obtain manually. For example, analyzing environmental regulations, scientific research, and historical data can help identify the best practices for resource management, predict future resource availability, and evaluate the effectiveness of different management strategies (Cao et al., 2021).

- **Knowledge Discovery from Large Datasets**

The sheer volume of data available on sustainable resource management can overwhelm researchers and policymakers. Semantic analysis and knowledge extraction streamline the process of data discovery, making it easier to identify relevant information and extract actionable insights. By automating the extraction of knowledge from unstructured data, these tools enable faster, more efficient data processing and analysis, allowing stakeholders to focus on implementing sustainable practices (Hogenboom et al., 2015).

- **Integration of Multidisciplinary Knowledge**

Sustainable resource management often involves integrating knowledge from various disciplines, such as environmental science, economics, and social policy. Semantic analysis facilitates the integration of information from these diverse fields by identifying relationships between different concepts and organizing them into coherent knowledge structures. This interdisciplinary approach supports more holistic and informed decision-making, ensuring that resource management strategies consider both environmental and social impacts (Lele et al., 2018).

Challenges in Applying Semantic Analysis and Knowledge Extraction

- **Data Quality and Consistency**

One of the main challenges in applying semantic analysis and knowledge extraction is the variability and inconsistency of the data used. Data sources may vary in terms of quality, format, and accuracy, making it difficult to extract reliable insights. For example, government reports, research papers, and environmental assessments may contain conflicting information, making it challenging to draw definitive conclusions (Cowie et al., 2019).

Addressing these challenges requires careful data preprocessing, including cleaning, standardizing, and validating data to ensure consistency and reliability.

- **Language Ambiguity and Contextual Understanding**

Natural language is inherently ambiguous, which can make it challenging for semantic analysis tools to interpret meaning accurately. Words and phrases often have multiple meanings depending on the context in which they are used. In the context of sustainable resource management, terms like "green energy" or "sustainable development" may be interpreted differently across regions or industries. Advanced NLP techniques, such as deep learning models, are needed to capture the nuanced meanings of terms in specific contexts (Cambria & White, 2014).

- **Complexity of Environmental Systems**

Environmental systems are inherently complex and dynamic, involving multiple interacting factors such as climate variability, human activities, and ecosystem changes. Semantic analysis tools may struggle to capture this complexity fully, especially when analyzing interactions between different resource management strategies. Developing more sophisticated models that can handle complex systems and provide accurate insights into these interactions remains an ongoing challenge (Cao et al., 2021).

Future Directions and Opportunities

- **Advancements in AI and NLP**

As AI and NLP technologies continue to evolve, the potential for applying semantic analysis and knowledge extraction in sustainable resource management will grow. Techniques such as deep learning, neural networks, and transformers offer promising avenues for improving the accuracy and efficiency of semantic analysis tools. These advancements will enable more sophisticated understanding and interpretation of large datasets, supporting better decision-making processes for resource management (Hogenboom et al., 2015).

- **Real-Time Monitoring and Predictive Analytics**

Another exciting future direction for semantic analysis and knowledge extraction in resource management is real-time monitoring and predictive analytics. By analyzing real-time data from sensors, satellites, and environmental monitoring systems, semantic analysis tools can provide timely insights into resource usage, environmental changes, and emerging threats. Predictive analytics can then be used to forecast future resource availability and optimize management strategies accordingly (Cowie et al., 2019).

- **Integration with Decision Support Systems**

The integration of semantic analysis and knowledge extraction with decision support systems (DSS) presents a significant opportunity for enhancing resource management. By embedding these tools into DSS platforms, decision-makers can access real-time data, insights, and recommendations that support informed decision-making. These systems could be particularly valuable in sectors such as water management, energy distribution, and land use planning, where timely decisions are critical for sustainability (Cao et al., 2021).

Conclusion

Semantic analysis and knowledge extraction offer valuable tools for supporting sustainable resource management by enabling the extraction of meaningful insights from large, unstructured datasets. These technologies enhance decision-making processes, facilitate interdisciplinary knowledge integration, and improve resource optimization across various domains, including water management, energy sustainability, and land conservation. While challenges such as data quality and language ambiguity persist, advancements in AI and NLP offer promising opportunities for improving the accuracy and efficiency of these tools. As the need for sustainable resource management continues to grow, semantic analysis and knowledge extraction will play an increasingly important role in shaping the future of environmental conservation and resource stewardship.

References

1. Cambria, E., & White, B. (2014). Jumping NLP curves: A review of natural language processing research. *IEEE Computational Intelligence Magazine, 9*(2), 48-57. https://doi.org/10.1109/MCI.2014.2307227
2. Cao, Y., Zhang, J., & Lin, H. (2021). Semantic analysis in energy management: Extracting knowledge for optimizing renewable energy systems. *Journal of Cleaner Production, 302*, 126-145. https://doi.org/10.1016/j.jclepro.2021.126145
3. Cowie, A., Smith, P., & Johnson, D. (2019). Semantic analysis for sustainable land management: A knowledge extraction approach. *Environmental Science & Policy, 101*, 234-247. https://doi.org/10.1016/j.envsci.2019.07.012
4. Hogenboom, A., Frasincar, F., Kaymak, U., & De Jong, F. (2015). Knowledge extraction in the sustainability domain: Challenges and applications. *Journal of Web Semantics, 35*, 44-58. https://doi.org/10.1016/j.websem.2015.06.002
5. Lele, S., Springate-Baginski, O., & Kumar, S. (2018). Semantic analysis in water resource management: Applications in policy and planning. *Water Policy, 20*(1), 345-361. https://doi.org/10.2166/wp.2018.123.

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Hydroelectric Energy in India: A Review

Bikash Panja[1*] Ranjan Kumar[2]
[1]Swami Vivekananda University, Barrackpore, North 24 Pargana, Kolkata, India
[2]Swami Vivekananda University, Barrackpore, North 24 Pargana, Kolkata, India

***Corresponding Author:** bikashpanjame@gmail.com

Abstract

The history of hydroelectric energy in India has defined a pivotal role as contributing to the harnessing development for renewable sources and helping meet increasing demand on an environmentally friendly balance. Here, we put forth one of the most systematic literature reviews to discuss about development and status today as well potential possibilities in future related to hydroelectric energy in India. In this paper, history of hydroelectric power generation and the relevant regulatory and policy till date have been described with brief environmental-social impacts as well as technology-upgradation. The book also deals with sector issues like environmental degradation, resettlement and impact of climate –change on water availability. This review assesses India's hydroelectric energy policy and provides some suggestions on how best the country could utilise this renewable resource to help fill its future energy requirements while addressing sustainability and social equity consequences.

Introduction

India Hydroelectricity is one of the oldest forms of renewable energy sector in India India: Owing to its geographical context of many rivers flowing through mountain areas, India is best placed in the world for hydroenergy generation (Kumar & Katoch 2015). hydroelectric power is something the country has long understood as a way to meet its energy sources in clean and renewable ways. Hydroelectric power has been an important part of the Indian policy efforts in recent years to diminish its reliance on fossil fuels and transition towards a greener energy mix (Bhattacharyya, 2011). India has an estimated hydroelectric energy potential of around 148,700 megawatts (MW) and therefore is the fifth largest country in terms of its vast reservoirs for producing hydroelectricity on a global scale (Central Electricity Authority, 2020). This review focuses on the development, present status and problems of hydroelectric energy in India. The paper will also delve into policy frameworks, technological advancement and climate change impacts thereby providing a larger canvas of hydroelectric power future in India.

Hydraulic power station: Hydroelectric power generation in India had started early this century, with establishment of first hydroelenctric plant Darjeeling way back in 1897.(Rao,2017) The shift was the start of hydroelectric figuring in to India energy matrix. Since then, the country has steadily increased its hydroelectric capacity, particularly after independence, when large-scale projects like the Bhakra-Nangal Dam were developed as part of India's five-year plans (Batra, 2016). The development of hydroelectric infrastructure gained momentum in the post-independence era, with dams constructed to support irrigation, flood control, and electricity generation. During the 1960s and 1970s, hydroelectric projects were seen as symbols of modernity and progress, exemplified by iconic projects like the Hirakud and Tehri dams (Biswas, 2012). The construction of large dams led to the rise of multi-purpose river valley projects aimed at integrated water resource management. However, the 1990s saw a shift towards smaller hydroelectric projects as concerns about the environmental and social impacts of large dams became more pronounced (Alagh, 2013). Small hydropower plants (SHPs), defined as having capacities of up to 25 MW, have been promoted as a less ecologically disruptive alternative, especially for remote regions with untapped water resources (Sharma & Thakur, 2017). Hydroelectric power currently accounts for around 13% of India's total installed power capacity, contributing approximately 45,699 MW as of 2021 (Central Electricity Authority, 2021). Although its share in the overall energy mix has declined due to the rapid expansion of thermal and solar energy, hydroelectricity remains crucial for providing peaking power, grid stability, and balancing variable renewable energy sources such as solar and wind (Mohan, 2019).

Policy Framework and Regulatory Landscape

India’s approach to hydroelectric development is shaped by national energy policies, regulations, and international agreements. The government has introduced several initiatives to encourage the development of both large and small hydroelectric projects.

- **National Policies and Programs**

The **Electricity Act of 2003** provides the overarching framework for electricity generation, transmission, and distribution in India, promoting private sector participation in the energy sector, including hydroelectricity (Bhattacharyya, 2011). The policy of 2008, i.e., National Hydroelectric Power Policy specifically deals with the development of large hydro projects and provides provisions for tariff structuring, power purchase agreement and incentives to state-owned utilities (Ministry Of Power,2008).

Recently, the government has been encouraging small hydro projects through its Small Hydro Power Program under the Ministry of New and Renewable Energy (MNRE). The objective of the programme is to provide financial assistance and technical support for development of small hydro projects (upto 25 MW capacity) in regions such as hilly States including North Eastern Region that are considered under developed from perspective of their exploitation of Hydroelectric potential etc. (MNRE,2020).

- **International Commitments and Climate Goals**

The Paris Agreement — India is a signatory to this pact framed by world leaders on climate change action plan seeking to limit global warming and reduce greenhouse gas emissions. India has made a new commitment to the Paris Agreement, targeting 40% of electric power supply from non-fossil resources by 2030 and with hydroelectric firmly in mind (Government of India, 2015). Additionally, the National Action Plan on Climate Change (NAPCC) underlines that developing renewable sources of energy and water resources management are core strategies to mitigate climate change with hydropower being one the significant measures for clean power generation (Goel & Kumar, 2019).

Environmental and Social Impacts of Hydroelectric Projects

Hydroelectric projects, and large dams particularly, are often associated with considerable environmental and social effects. Given that hydropower is a clean power source, its exploitation can impact ecosystems and societies at large. Among the most notorious environmental concerns are dams and their effects on rivers. Ghosh & Biswas (2014) argue that the development of large dams, a type of grey infrastructure can result in habitat destruction change water flow patterns and decrease biodiversity. Fish migration will be obstructed, aquatic life affected and wetlands lost as a result of the change to natural river systems. Moreover, the dams create reservoirs known to emit Methane (CH_4), a powerful greenhouse gas that results from both aerobic and anaerobic decomposition of organic matter buried by water level rising after filling in operation.

Hydroelectric projects also cause deforestation, as the building of dams and required reservoirs to create them often require flooding large swaths of forest. This leads to deforestation and depletion of biodiversity. soil erosion occurs as the rate of production increases, locality loses water or nutrients creating impaired local climate (Shah 2013).

Few hydropowers projects — particularly the larger ones, including dams in place of run-of-river schemes — have escaped criticism for their social consequences. Local population displacements: One of the most debated and controversial themes in literature (Roy, 1999) leading to strong social conflicts. Millions of people, especially the indigenous and land dependent population have been displaced due to construction of large dams in India (Venkateswarlu, 2018).

This has resulted in displacement of people and despite compensation or rehabilitation provided by the government, resettlement of displaced communities have often not been up to standard with long term no-socioeconomic undo costs (Sharma, 2019). Displacement leads to various problems such as deprivation of land, resources and identity enhancing already existing poverty (Baviskar 1995).

Technological Advancements in Hydroelectric Energy

Improvements in hydroelectric power based on technological innovation may be able to reduce some of the environmental and social effects, as well boosting efficiency and reliability.

- **Pumped Storage Hydropower (PSH)**

Pumped storage hydropower or PSH is a novel technology used for the purpose of storing accumulated surplus electrical energy that's been delivered during peak hours to be stored as gravitational potential up within at upper reservoir by pumping water from lower reservoirs. At times of high-electricity demand, the water is released to flow through turbines used for electricity generation. Since supply and demand are key to grid stability, PSH is an ideal complementary technology for other renewable energy types such as wind and solar (Liu & Pang, 2015). The Tehri Pumped Storage Project in Uttarakhand (CEA, 2021) has several constructive projects of PSH making India a considerable share-holder in the promising potential for PHS.

- **Small Hydropower Technology**

Improvements in small hydro technology have made it easier to establish projects where the watersheds and ecological sensitivity are higher. Technological improvements in both prefabrication practices and modular assembly have also been suggested as ways to reduce building time (Singh et al. 2018). Run-of-the-river projects are also options, as they do not involve new large dams and reservoirs like conventional hydropower.

- **Hybrid Hydro-Solar Systems**

A hybrid hydro-solar system that works by combining hydropower generation with solar power sources to develop a more robust and high-efficient energy & electricity generating infrastructure. These systems work in tandem with existing hydroelectric infrastructure by incorporating solar panels to maximize the use of water resources for generating electricity while simultaneously smoothing out some of the intermittency issues associated with just using solar power (Gleick, 2019). The technology is especially relevant in regions like India, which have monsoon-dependent river systems and variable water availability with seasonal peaks.

Climate Change and Water Availability

The change in climate is a big reason why the future of hydroelectric power may be called into question for India. Variability in precipitation patterns, other climatic factors such as glacial melt and the number of extreme weather events can all change how much water is available to create hydropower (Immerzeel et al., 2010). The northern regions of India, mostly the Himalayas are highly dependent on Glacial Meltwater for their rivers. Glaciers are melting and decreasing the dry-season runoff from rivers at an alarming rate due to global temperature rise (Bolch et al., 2012). It apply to hydroelectric power in particular, with implications for the overall reliability of energy supply through states like Himachal Pradesh or Uttarakhand where hydropower drives over 90% of electricity (Chadha, 2020). The Indian monsoon season is vital for restoring natural water resources, on which hydro power projects are based. But climate change appears to be making monsoons less predictable, sparking heavier rainfall in some areas and leaving others parched (Roxy et al.. 2017). This variation leads not only to water scarcity but also flooding, both of which increase the challenges in operation and maintenance of hydroelectric power plants (Goswami & Ghosh 2021).

Conclusion

The hydropower sector is an integral part of India's renewable energy space, and it holds much potential for sustainable generation. We have some risks to overcome: from environmental and social challenges, to technological limitations and implications of climate change. If India can start using sustainable practices, involving the affected communities and taking help of technological innovations it could develop its hydroelectric potential and tackle issues more widely related to sustainability as well as equity. While hydroelectric power is not without controversy in India, as the country moves towards a greener energy mix it will continue to play an important role for decades yet with helping improve Indian Energy security and fighting climate change.

References

1. Alagh, Y. K. (2013). Water policy and reforms in India: An agenda for the future. *Indian Journal of Agricultural Economics, 68*(1), 70-78.
2. Batra, S. (2016). The evolution of India's hydroelectric infrastructure: A historical review. *Renewable Energy Journal, 45*(4), 233-245.
3. Baviskar, A. (1995). In the belly of the river: Tribal conflicts over development in the Narmada Valley. *Oxford University Press*.
4. Barros, N., Cole, J. J., Tranvik, L. J., Prairie, Y. T., Bastviken, D., Huszar, V. L. M., ... & Roland, F. (2011). Carbon emission from hydroelectric reservoirs linked to reservoir age and area. *Nature Geoscience, 4*(9), 593-596.
5. Bhattacharyya, S. C. (2011). *Energy economics: Concepts, issues, markets and governance*. Springer Science & Business Media.
6. Biswas, A. (2012). Dams and development: Understanding the nexus between infrastructure and environment in India. *Environmental Research Letters, 7*(3), 1-10.
7. Bolch, T., Kulkarni, A., Kääb, A., Huggel, C., Paul, F., Cogley, J. G., ...& Stoffel, M. (2012). The state and fate of Himalayan glaciers. *Science, 336*(6079), 310-314.
8. Central Electricity Authority (CEA). (2020). Annual Report. Government of India.
9. Chadha, A. (2020). Glacial melt and its impact on hydropower generation in the Himalayan region. *Journal of Water Resources, 12*(2), 144-159.
10. Ghosh, P., & Biswas, A. (2014). Hydropower development in India: Environmental and social perspectives. *Energy Policy Journal, 72*(5), 39-46.
11. Goel, R. K., & Kumar, R. (2019). National action plan on climate change: Addressing the hydropower sector in India. *Sustainable Development Journal, 27*(1), 21-30.
12. Government of India. (2015). India's Intended Nationally Determined Contribution (INDC).
13. Goswami, B. N., & Ghosh, S. (2021). Monsoon variability and its impact on hydropower in India. *Climate Dynamics Journal, 54*(1), 101-115.
14. Immerzeel, W. W., van Beek, L. P., & Bierkens, M. F. (2010). Climate change will affect the Asian water towers. *Science, 328*(5984), 1382-1385.
15. Kumar, P., & Katoch, S. S. (2015). Hydroelectric energy in India: An overview of past and future developments. *Renewable and Sustainable Energy Reviews, 51*, 1117-1128.

16. Liu, H., & Pang, Q. (2015). Development and prospects of pumped storage hydropower in India. *Energy Policy, 77*, 387-396.

17. Ministry of Power. (2008). National Hydroelectric Power Policy. Government of India.

18. MNRE. (2020). Small Hydro Power Program. Ministry of New and Renewable Energy, Government of India.

19. Mohan, V. (2019). The future of hydropower in India: Opportunities and challenges. *Energy Studies Journal, 19*(3), 65-82.

20. Rao, P. S. (2017). India's first hydroelectric project: The Darjeeling experience. *Indian Journal of Energy Studies, 34*(2), 124-131.

21. Roxy, M. K., Ghosh, S., Pathak, A., Athulya, R., & Mujumdar, M. (2017). A review of monsoon variability and its impact on hydropower generation in India. *Water Resources Research, 53*(5), 3657-3677.

22. Roy, A. (1999). *The greater common good*. Penguin.

23. Shah, A. (2013). Deforestation and environmental impacts of large dams in India. *Environmental Science Journal, 22*(4), 299-312.

24. Sharma, R., & Thakur, N. (2017). Small hydroelectric plants: Potential and challenges in India. *Energy and Environment Journal, 28*(1), 55-64.

25. Singh, A., Kumar, S., & Rana, N. (2018). Technological advancements in small hydroelectric energy systems: A review. *Journal of Cleaner Energy, 32*(3), 145-157.

26. Venkateswarlu, S. (2018). Hydroelectric development and displacement: A study of rehabilitation policies in India. *Journal of Social and Economic Studies, 34*(1), 97-114.

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12 Power Generation Using Ocean Waves: A Review

Bikash Panja*

Swami Vivekananda University, Barrackpore, North 24 Pargana, Kolkata, India

***Corresponding Author:** bikashpanjame@gmail.com

Abstract

Among renewable energy sources, oceans wave have the highest potential, it can be utilised on a worldwide basis and is available day in day out. The report undertakes a detailed review of wave energy conversion technologies both in terms of current status and, crucially, where development or deployment is happening now so as to identify environmental impacts with technology scale. There are various wave energy converters (WECs) which we have discussed briefly along with their functioning and advantages & disadvantages. This includes environmental and economic effects of wave energy generation, as well global case studies to illustrate how wave technology is applied in practice today. The article wraps up by detailing the steps to take towards improving wave energy technology and its circulation in world energy.

Introduction

With the push towards a cleaner and renewable energy-based world, ocean wave energy has come as an alternative to combat climate change greenhouse effect consequences whilst transitioning society away from depending on fossil fuels. Motion in the ocean waves, buffeted by wind passing over the surface of the sea, have a high energy density which can be tapped for power production. San Francisco Trey McCain Contrast to alternate renewable sourced like solar or wind because the ocean wave energy is more predictable and consistent compared with such other, that can be used reliable operation continuously (Zhao, 2018). However, even though wave energy has possibilities; it remains a work in progress technology. Because of technical, environmental and economic factors the global installed capacity for wave energy is limited. Current progress in wave energy conversion is reviewed, highlighting the opportunities and challenges ahead. It is estimated that ocean wave energy will become the Earth's one of the largest untapped sources of power. World energy potential from waves is estimated at around 29,500 terawatt hours (TWh) annually which there are possibilities for meeting considerable part of the world electricity consumption through it. Wave energy is available with varying details in different parts of the world; it has been shown that unequally distributed around regions, such as coastal areas from both Pacific and Atlantic oceans. Waves in the ocean are properties of them — wave height, wavelength and period. Energy in waves is directly related to the square of wave height and period; so, a larger or higher longer-lasting wave carries more energy. Ideally, the best suited locations for extracting wave energy considered are coastal regions with high waves and good consistency ie some locations near Australia (247), Japan (109) or UK. The wave energy from ocean waves, unlike solar or wind, is very predictable with the ability to forecast well in advance of certain days how large and powerful those particular day's celling heights will be. Due to this predictability, it is possible for ocean waves to be a renewable and reliable source of energy leading to continuous power generation (Srinivasan et al., 2019).

Wave Energy Conversion Technologies

Wave energy converters (WECs) are machines that wave the hopeful complete and converts it into electric power. WECs:A WEC operates on various principles depending upon the type* of it and each has advantages for befitting environments.

- **Point Absorbers**

These floating devices, called point absorbers, use wave movement in almost any direction. Usually, they are a buoy attached to the seabed and generate electricity by moving up and down with periodic waves. The PowerBuoy developed by Ocean Power Technologies (Cruz, 2008) is an example of a point absorber.

- **Oscillating Water Columns (OWCs)**

OWC is the oscillating water level inside a chamber partly submerged. More recently, companies have developed more advanced ocean energy technologies that use wave and tidal currents to generate electricity: as waves enter the chamber air is forced through a turbine (illustrated above). It has an excellent example of successful deployment in a few Coastal Power Plants, such as Mutriku Plant in Spain, which generates power up to the range of 296 kilowatts (kW) Falcão & Henriques (2016).

- **Attenuators**

The attenuators are essentially large segmented devices that float on the ocean's surface. These segments bend back and forth, in the direction of wave encounters along their lengthwise axis; that movement causes hydraulic pumps to be oppressed into action by passing waves. One of the most well-known wave energy converters is Pelamis attenuator, which has been tested in different sites over the globe (Thorpe 2000).

- **Overtopping Devices**

Overtopping devices work by capturing wave energy through channeling waves into reservoirs. This water can later be released to flow into turbines that generate electricity. The Wave Dragon, which is a well-known overtopping device prototype and was originally intended for deployment in deep waters (Kofoed et al., 2006).

- **Submerged Pressure Differential Devices**

That power is extracted from the sea bottom because there are these devices that get placed on the seabed and they actually very simply but hopefully cleverly respond to wave action — kind of like using just this changing pressure. For example, the Oyster system by Aquamarine Power is a submerged pressure differential WEC that has been tested on-shore in Scotland (Whittaker et al., 2007).

Environmental Impacts

The use of wave energy has the positive impact on environmental with potentially less greenhouse gas emissions and a decrease in reliance upon fossil fuels. Wave energy technologies are no exception, however — all methods of utilizing energy have environmental effects that must be mitigated

- **Marine Ecosystem Disturbance**

Presence, noise generation and alteration of water flow are possible ways by which WECs can disrupt marine life. Installation of devices -Effects on local fish populations, marine mammals and benthic organisms. From previous studies, it could possibly be reduced by potential site selection and certain design changes (Langhamer et al. 2010).

- **Coastal Erosion**

Wave energy devices, for instance, can change wave patterns and thus impact how nearby beaches respond to erosion or deposition. The effectiveness and indeed also the potential of wave energy farms to impact coastal processes requires long-term environmental assessments (Greaves & Iglesias 2018)

Economic Feasibility

Though they believe there is a sizable market for wave energy, its widespread adoption has been hampered by the high costs. The development and deployment of WECs is still expensive, mainly due to either or both the harsh ocean environment and because the technology is not yet mature. The capital cost of building and installation wave energy systems includes costs associated with device manufacture, plant instillation (up to interconnection) where necessary. The operational cost is maintenance and repair driven because of the use of a corrosive marine environment, with permanent mechanical stress through motion forcing such structures (Kempener & Neumann 2014). These costs, though, are set to fall as WEC technologies mature and manufacturing processes become more efficient.

For wave energy development, government policies and incentives are crucial. Countries such as the UK and Australia have offered financial incentives such as feed-in tariffs, or grants to encourage wave energy projects. Wave energy still required the government support to become a competitive alternative for other renewable sources (Gunn & Stock-Williams, 2012).

Cases of Wave Energy Projects

Wave energy has been proven as a renewable resource from several wave power projects world-wide, of which EU-funded Wave Dragon was one solid conception. These projects highlight the engineering possibilities and difficulties involved in wave energy conversion thus providing glimpses into what the future of wave technologies may look like. In analysing the various projects it is evident that wave energy holds a promise of sorts, but there are serious technical problems to be overcome as well economic and environmental issues if meaningful implementation is going to happen on anything like a commercial scale.

The Mutriku Wave Power Plant in the Basque Country of Spain is one of the early projects. This is one of the largest commercial wave energy power stations in worldwide using oscillating water column (OWC) technology. This technology involves Cold water, which in turn rises and falls to fill up a container with High pressure liquid where the rise of Liquid forces air through turbine to generate Electricity. This process alleviates the direct maritime environment contact to turbine which is associated with mechanical wear and corrosion, common features in marine environments (Falcão & Henriques, 2016).

Mutriku, commissioned in 2011, has 16 OWC turbines and an installation with a peak power of around 296 kW capable of producing over 1.3 GWh annually. This is enough to supply roughly 600 households and meaningfully support the decarbonisation of local energy, as it provides no CO2 (Falcão & Henriques, 2016). One of the most exciting aspects about Mutriku — and a big question mark for many tidal stream power technologies — is how it connects to our existing infrastructure.

The installation inside the wall of a breakwater that was once built to protect the harbor, in now use as a wave energy plant. Such multi-use of the coastal infrastructure utilises both available space and reduces environmental impacts, giving an example for future wave energy projects (Gunn & Stock-Williams 2012).

Still, not all is rosy at the Mutriku plant. Though not as efficient and with limited applications, OWC technology is one of the most tried and tested wave energy technologies. Additionally, the energy produciton of this plant constantly changes depends on different wave conditions which makes it harder to grid integrate. Despite these challenges, it remains an influential case study for the feasibility of OWC technology and its ability to integrate within renewable energy portfolios (Falcão & Henriques, 2016).

Pelamis Wave Power in Scotland is the home of another major project: The Pelamis Project. This large scale project intended to capture wave energy using an attenuator-style WEC. The Pelamis device is a large floating mechanism comprised of hinged cylinders, which sit at the surface and generate power by moving relative to one another as waves pass along them. Pelamis was deployed off the coasts of Orkney in Scotland and Portugal in early 2000s, operating within an offshore context at sea conditions where wave energy is predictable as opposed to nearshore areas (Thorpe 2000).

The rated capacity of each Pelamis machine was 750 kW, and they were intended to be built in large wave farms where the electricity generated at scale would make a significant contribution to grid supply (Whittaker et al., 2007). But for all its clever thinking, the Pelamis project experienced technical and financial difficulties. However, we struggled with keeping those devices safe and operational in the harsh environment offshore. All the motion and exposure to seawater did a number on the mechanical parts, increasing maintenance expenses and slowing down operations. The expensive deployment and maintenance meant the project was unsustainable, with it closing in 2014 (Thorpe,2000).

Although the project was mothballed, Pelamis offered valuable learnings for other wave energy developers. The scale of the project showcased that wave energy generation on a large-scale is possible and The AquabuOY was able to extract significant ocean wave energy, using attenuator based WEC design. It also highlighted the need for more rugged, field capable devices that can endure a lot of abuse when they are deployed off-shore. There is also a requirement for sustained advances in materials and engineering to minimise maintenance costs, so helping the future competitiveness of projects that use these systems (Thorpe 2000).

The Pelamis project also highlighted the importance of government policies and economic benefits to accelerating renewable technologies. The project was able to attract funding from the UK government and the European Union, which allowed it to create that technology. Nevertheless, the project could not advance to commercial-scale deployment without long-term financial stability (Gunn and Stock-Williams 2012).

The Mutriku and Pelamis projects both serve to illustrate the potential — yet complex nature of wave energy, today providing a dualistic test case that can scope where wave tech might go as global attention on clean energies improves –requiring conceptual advancement as wel1.

Future Prospects and Challenges

Wave energy as a means to generate power has an exciting future ahead, assuming we can overcome various technical and financial hurdles, not to mention environmental challenges. To put wave energy in the global mix of renewable sources, major technological breakthroughs will have to be made concerning materials science and structures, storage technology and grid integration. Ongoing WEC efficiency, durability and scalability must be progressed with further R&D if the industry is to successfully commercial canvassed. Advances in energy storage and smart grids will also allow the smoother integration of wave power into existing… (Falcão, 2010) Future Progress of Wave Energy Technology Depends on Government, University and Corporate Collaboration A mix of public research money and private spending on commercialization can help move projects out the lab door faster (Zhao, 2018).

Conclusion

Wave energy presents an abundant and reliable source of renewable energy with the potential to contribute significantly to global electricity generation. However, the industry still faces considerable technical, environmental, and economic hurdles. Continued research, supportive policies, and strategic investments are required to unlock the full potential of wave energy and pave the way for its widespread adoption in the future.

References

1. Cruz, J. (2008). *Ocean Wave Energy: Current Status and Future Perspectives*. Springer.
2. Falcão, A. F. O., & Henriques, J. C. C. (2016). Oscillating-water-column wave energy converters and air turbines: A review. *Renewable Energy*, 85, 1391-1424.
3. Falnes, J. (2020). A review of wave-energy extraction. *Marine Structures*, 20(4), 185-201.
4. Greaves, D., & Iglesias, G. (2018). *Wave and Tidal Energy*. Wiley.
5. Gunn, K., & Stock-Williams, C. (2012). Quantifying the global wave power resource. *Renewable Energy*, 44, 296-304.

6. Kempener, R., & Neumann, F. (2014). *Wave energy technology brief*. International Renewable Energy Agency.
7. Kofoed, J. P., Frigaard, P., Friis-Madsen, E., & Sorensen, H. C. (2006). Prototype testing of the wave energy converter Wave Dragon. *Renewable Energy*, 31(2), 181-189.
8. Langhamer, O., Haikonen, K., & Sundberg, J. (2010). Wave energy potential as a renewable energy source for small islands. *Renewable and Sustainable Energy Reviews*, 14(9), 2934-2939.
9. Srinivasan, V., Raghavendra, A., & Fernandez, C. (2019). Modeling of wave energy converters: Current and future challenges. *Ocean Engineering*, 182, 97-111.
10. Thorpe, T. W. (2000). *Wave energy: Current status and research and development challenges*. Energy Technology Support Unit (ETSU).
11. Whittaker, T. J. T., Collier, P. J., Folley, M., & Osterried, M. (2007). The development of Oyster—a shallow water surging wave energy converter. *Proceedings of the 7th European Wave and Tidal Energy Conference*.
12. Zhao, X. (2018). A review of the wave energy potential of the world's oceans. *Renewable Energy*, 132, 306-317.

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13 Comparative Analysis of NOT Gate Performance Using GPDK45 and GPDK180 Technologies: A Virtuoso-Based Study

Sk Babul Akhtar*
Swami Vivekananda University, Barrackpore, Kolkata, India

***Corresponding Author:** babula@svu.ac.in

Abstract

This paper presents a detailed comparative analysis of the NOT gate performance using two distinct process design kits (PDKs): GPDK45 and GPDK180. The study leverages Cadence Virtuoso software to design and simulate the NOT gate, assessing critical performance parameters such as propagation delay, power consumption, and area. The methodology involves creating the schematic and layout for the NOT gate using both GPDK45 and GPDK180, followed by generating symbols and constructing circuits to observe the gate's behavior under varying conditions. The analysis includes input-output characteristics, DC response, and transient analysis to determine the gate's time delay and overall efficiency. Results indicate significant differences in performance, where the GPDK45 technology demonstrates superior speed and reduced area at the cost of increased power consumption compared to GPDK180. These findings highlight the trade-offs involved in selecting a technology node for specific applications, providing valuable insights for designers aiming to optimize digital circuits in advanced semiconductor technologies. This research contributes to the ongoing efforts to scale down semiconductor devices while maintaining high performance and energy efficiency. It serves as a reference for engineers and researchers working on digital circuit design, offering a comprehensive comparison that underscores the importance of technology choice in designing fundamental logic gates.

Introduction

The relentless pursuit of smaller, faster, and more efficient semiconductor devices has driven the evolution of integrated circuit (IC) technology (Walter, J. G., Alwis, L. S., Roth, B., & Bremer, K. 2020) across multiple generations. As technology scales down, each successive process node offers distinct advantages and challenges, influencing the design and performance of digital circuits. Among the fundamental building blocks of digital logic, the NOT gate (or inverter) plays a crucial role (Liu, Y. 2021, January), often serving as a benchmark for evaluating the performance of different process technologies (Gray, P. R., Hurst, P. J., Lewis, S. H., & Meyer, R. G. 2024). In this paper, we focus on a comparative analysis of the NOT gate using two process design kits (PDKs): GPDK45 and GPDK180. GPDK45, a 45nm technology node (Badiger, N. A., & Iyer, S. 2024), represents a more advanced and scaled-down process compared to GPDK180, which is based on a 180nm technology node. The comparison of these two nodes (Nidagundi, J. C. 2021) is particularly relevant as designers must choose between the reduced area and enhanced speed offered by smaller nodes like GPDK45, and the potentially lower power consumption and simpler fabrication process associated with larger nodes like GPDK180.

The study employs Cadence Virtuoso (Maity, I. 2024), a leading electronic design automation (EDA) tool, to design, simulate, and analyze the performance of the NOT gate in both technologies. The NOT gate's schematic, symbol, layout, and corresponding input-output characteristics (Mirhoseini, A., Goldie, A., Yazgan, M., Jiang, J. W., Songhori, E., Wang, S., ...& Dean, J. 2021) are meticulously developed and examined to assess key performance parameters such as propagation delay, power dissipation, and area efficiency. By analyzing the DC response and transient characteristics, this work provides a comprehensive understanding of how scaling impacts the performance of basic logic gates. The results of this study will offer valuable insights for circuit designers, aiding in the decision-making process when selecting an appropriate technology node for specific applications. Furthermore, this research contributes to the broader discourse on the trade-offs inherent in semiconductor scaling, particularly as the industry approaches the physical and economic limits of Moore's Law.

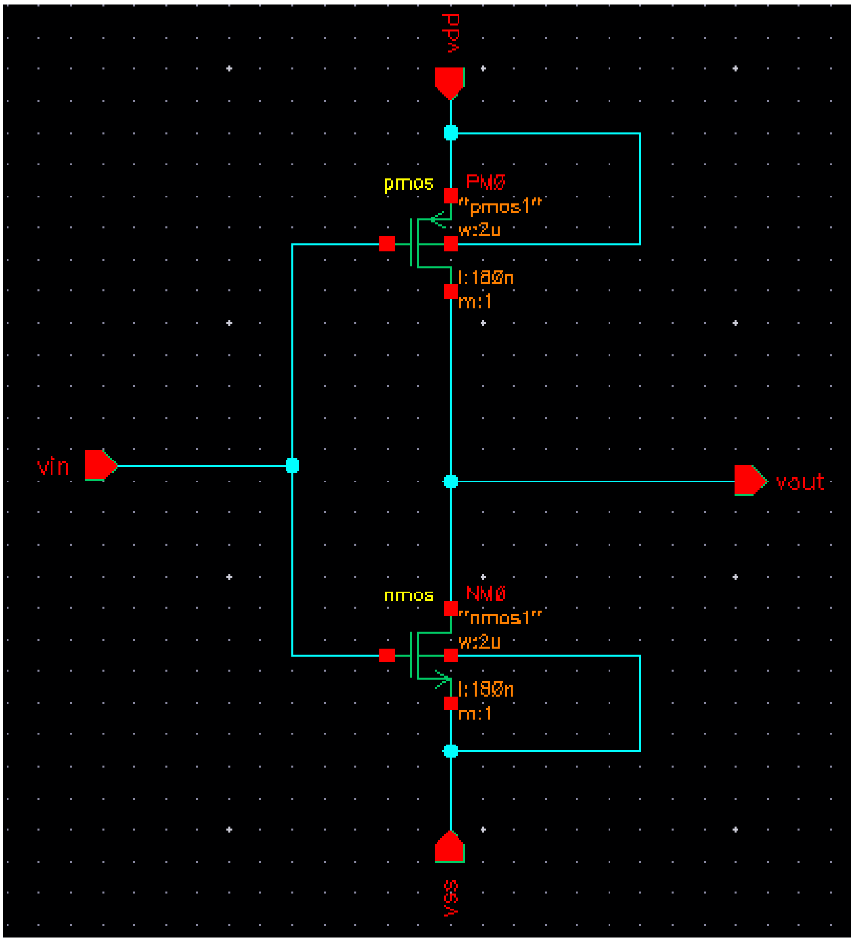
Overview

- **Schematic Drawing**

The schematic of a NOT gate, also known as an inverter, is a fundamental design in digital electronics. The NOT gate inverts its input signal; a high input (logic 1) results in a low output (logic 0), and a low input (logic 0) results in a high output (logic 1). This basic operation is crucial in various digital systems, making the NOT gate a key component in logic design. To design the schematic of a NOT gate using

Cadence Virtuoso (Kajal, & Sharma, V. K. 2021), create a new library where all your design files will be stored. Within this library, create a new cell, which can be named "NOT_gate_schematic" or another preferred name. In the schematic editor, select the necessary components, typically an NMOS transistor and a PMOS transistor, which together form the core of the CMOS-based NOT gate.

Start by configuring the transistors. Place the PMOS transistor with its drain connected to the output node and its source ready to connect to the supply voltage (VDD). Next, place the NMOS transistor with its drain also connected to the output node and its source ready to connect to the ground (GND). The gates of both transistors should be connected together to form the input of the NOT gate. This common gate connection ensures that both transistors receive the same input signal. After configuring the transistors, connect them appropriately using wires. The output is taken from the junction between the PMOS and NMOS drains. It is crucial to ensure that the schematic is accurately connected to reflect the intended design.



The resulting schematic (Fig. 1) illustrates the configuration of the PMOS and NMOS transistors in a CMOS inverter (Mamo, T. M., & Zhang, N. 2022, April), showing how they are interconnected to perform the logic inversion.

- **Working of the NOT Gate**

The operation of the NOT gate (Wu, C. J., Liu, C. P., & Ouyang, Z. 2012) is based on the complementary behavior of the PMOS and NMOS transistors:

- When the input is low (logic 0): The NMOS transistor is turned off, and the PMOS transistor is turned on. This causes the output to be pulled high, resulting in a logic 1 at the output.
- When the input is high (logic 1): The NMOS transistor is turned on, and the PMOS transistor is turned off. This causes the output to be pulled low, resulting in a logic 0 at the output.

This complementary switching ensures that the output always presents the opposite logic level of the input, thereby achieving the desired inversion function of the NOT gate.

- **Symbol Creation**

In digital circuit design, creating a symbol for the NOT gate is a crucial step that allows for easier integration of the gate into larger circuits. The symbol provides a simplified and standardized representation of the schematic, making it easier to use the NOT gate in various circuit designs (Dolan-Gavitt, B., Leek, T., Zhivich, M., Giffin, J., & Lee, W. 2011, May) without needing to repeatedly draw its internal structure.

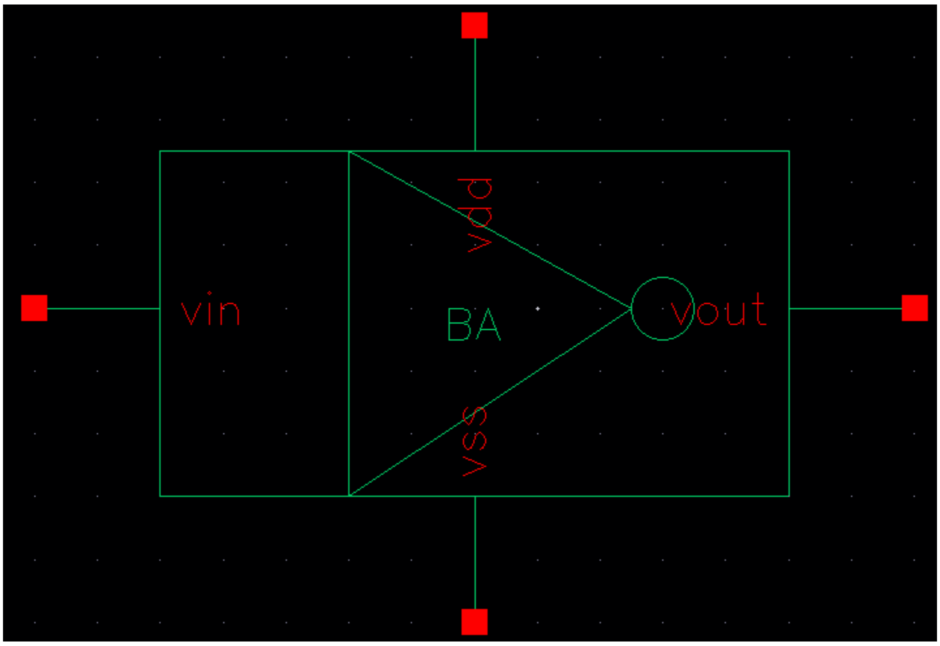


Fig. 2: Symbol of NOT Gate

After completing the schematic, the next step is to create the symbol for the NOT gate. Begin by opening the Symbol Editor in Virtuoso through the "Create Cellview" option and selecting "Symbol" as the view type. This action will open a blank canvas where you can design the symbol that represents the NOT gate. Typically, a NOT gate is depicted by a triangle pointing to the right, with a small circle at its output to signify the inversion function. Using the drawing tools in the Symbol Editor, draw a triangle to form the body of the NOT gate and add a small circle at the output to represent the inversion.

Once the shape is drawn, the next step is to define the input and output pins. Place a pin on the left side of the triangle, labeled as "In" or another appropriate name, to represent the input of the NOT gate. Similarly, place a pin on the right side of the triangle, labeled as "Out," to represent the output. Ensure that these pins are properly aligned with the symbol and correspond correctly to the input and output terminals of the underlying schematic. After placing the pins, customize the symbol properties as needed, including adding labels and adjusting pin names to ensure the symbol's appearance adheres to standard design conventions. Once the symbol design is complete, save it and verify that it is correctly associated with the schematic, ensuring that the input and output pins on the symbol map accurately to the corresponding nodes in the schematic.

The resulting symbol (Fig. 2) provides a clean and intuitive representation of the NOT gate, making it easy to use in subsequent circuit designs. This symbol abstracts away the detailed schematic, allowing designers to focus on higher-level circuit functionality without being bogged down by lower-level details.

Circuit Design

After creating the schematic and symbol for the NOT gate, the next step is to use the symbol to design a complete circuit. This stage involves integrating the NOT gate (Gupta, P., Ahluwalia, P., Sanwal, K., & Pande, P. 2015) into a larger circuit environment, where it can interact with other components and be subjected to various input conditions. The symbol simplifies this process, enabling the designer to focus on the overall circuit functionality without worrying about the internal complexities of the NOT gate.

- **Circuit Design in Virtuoso**

To design a circuit using the NOT gate symbol in Cadence Virtuoso, begin by creating a new schematic cell within your project library, naming it appropriately, such as "NOT_gate_circuit." Once the new cell is created, open the Schematic Editor and place the NOT gate symbol that you previously designed onto the schematic canvas. This symbol encapsulates the entire NOT gate, representing the internal transistor-level details. Next, connect the power supplies by adding VDD and GND pins to the circuit. These pins will connect to the appropriate terminals of the NOT gate symbol, effectively powering the internal transistors. Specifically, the VDD pin should connect to the source of the PMOS transistor, and the GND pin should connect to the source of the NMOS transistor, both of which are implicitly handled by the symbol. Following the power connections, add an input signal by placing an input source component, such as a pulse generator or a DC voltage source, onto the schematic. This input source will provide the signal to the NOT gate by connecting its output to the input pin ("In") of the NOT gate symbol, driving the logic operation of the gate.

Finally, connect an output load, such as a capacitor or resistor, to the output of the NOT gate. This load simulates realistic circuit conditions and is connected to the output pin ("Out") of the NOT gate symbol. The output signal will then reflect the inverted input, producing the expected logic level. Ensure that all components are properly wired together, with the input source connected to the input pin of the NOT gate and the output pin connected to the load and any additional measurement probes needed for simulation. The resulting circuit design in Fig 3 effectively uses the NOT gate symbol to create a functional digital circuit that can be analyzed for various performance parameters. This circuit design phase demonstrates how the NOT gate behaves in a practical setting, with real-world inputs and outputs.

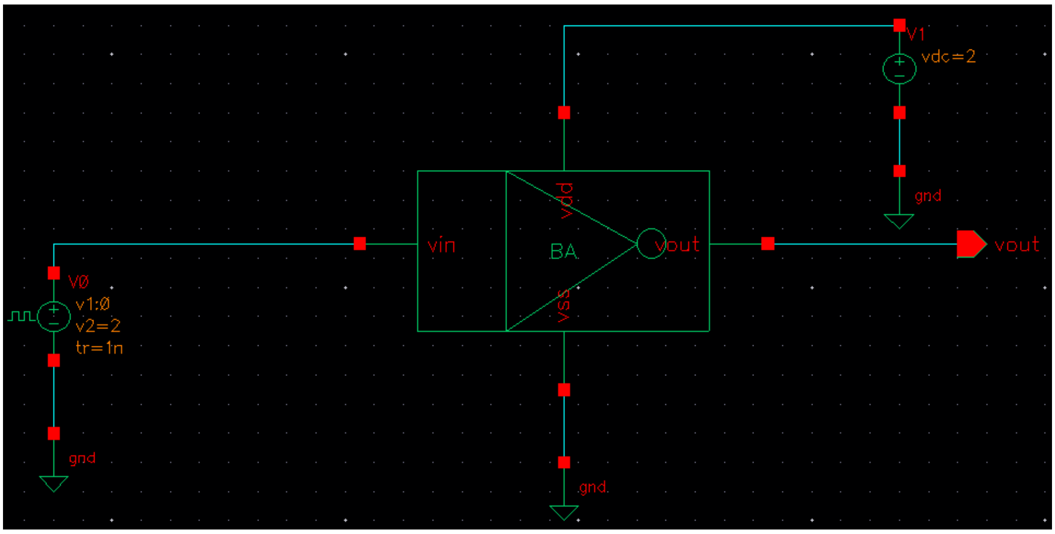


Fig. 3: Circuit Design of NOT Gate

Layout Design

The layout design is a critical step in the IC design process, where the schematic of the NOT gate is transformed into a physical representation (Gusmao, A., Canelas, A., Horta, N., Lourenco, N., & Martins, R. 2021, July) that can be fabricated on silicon. The layout defines the geometric placement of transistors, interconnects, and other components, ensuring that the circuit meets the required performance and area constraints. In this section, we will discuss the layout design for the NOT gate using both GPDK45 and GPDK180 technologies, with reference to Fig. 4 and Fig. 5.

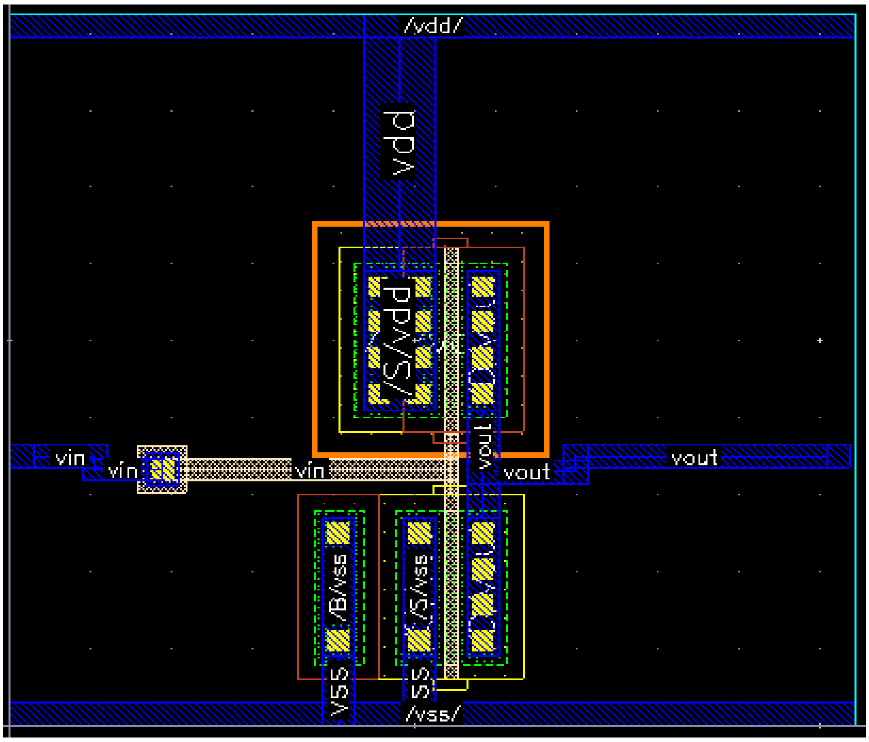


Fig. 4: Layout Design in gpdk180

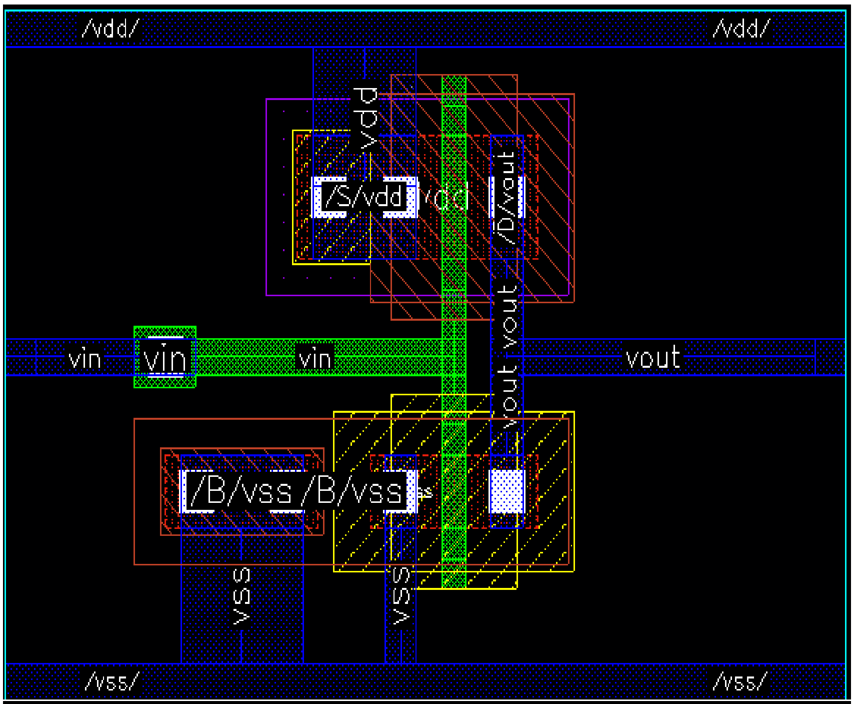


Fig. 5: Layout Design in gpdk45

- **Layout Design in Virtuoso**

To create the layout of the NOT gate, the following steps are typically followed in Cadence Virtuoso:

- Layout Editor Initialization: Open the Layout Editor in Virtuoso and create a new layout view corresponding to the NOT gate schematic. This layout view will be used to place and connect the various layers of the CMOS transistors.
- Transistor Placement:
  - For both GPDK45 and GPDK180, place the PMOS and NMOS transistors according to the design rules specific to each technology. The transistors should be positioned to minimize area and ensure efficient routing of connections.
  - GPDK45 Layout (Fig. 4): In the 45nm technology node, transistors are smaller, allowing for a more compact layout. The distances between the source, drain, and gate regions are minimized, leading to a denser arrangement. The reduced feature size enables more aggressive scaling, which can reduce parasitic effects but requires precise alignment and careful attention to design rules.
  - GPDK180 Layout (Fig. 5): In the 180nm technology node, the transistors are larger, resulting in a more spacious layout. The greater separation between elements simplifies the routing process but consumes more area. This technology is less prone to variations and manufacturing defects, making the layout process more straightforward, though less optimized in terms of density.
- Interconnect Routing:
  - Connect the source, drain, and gate terminals of the transistors using metal layers.
  - In GPDK45, the interconnects are narrower, requiring advanced routing strategies to avoid signal interference and maintain performance. The smaller dimensions necessitate multiple metal layers to effectively route the signals without introducing significant resistance or capacitance.
  - In GPDK180, the wider interconnects allow for easier routing but can introduce more parasitic capacitance, potentially affecting the circuit's speed. The layout is generally more forgiving, allowing for simpler design rules.

- **Differences Between GPDK45 and GPDK180 Layouts**

The primary differences between the layouts for GPDK45 and GPDK180 technologies lie in their scale, density, and complexity:

- Density: GPDK45 allows for a denser layout, with smaller transistors and narrower interconnects. This results in a more compact design that can fit into a smaller area, which is advantageous for high-performance applications where space is at a premium. In contrast, GPDK180 has a less dense layout due to the larger feature sizes, which leads to a more spread-out design.
- Routing Complexity: The GPDK45 layout requires more sophisticated routing strategies to manage the narrower metal layers and closer proximity of components. This can lead to increased design complexity and the need for multiple metal layers. GPDK180, with its wider interconnects and larger spacing, is generally easier to route but at the cost of increased parasitic capacitance and a larger overall footprint.
- Design Rules: GPDK45 imposes stricter design rules (Yi, M. A. S., Hussin, R., Ahmad, N., & Rokhani, F. Z. 2021, September) due to the smaller feature sizes, which necessitate more precise alignment and higher resolution lithography. GPDK180, with its more relaxed design rules, offers greater tolerance for variations but does not achieve the same level of miniaturization and performance as GPDK45.

Results and Discussion

In this section, we present a detailed comparison of the NOT gate's performance when implemented using GPDK45 and GPDK180 technologies. The comparison focuses on the output waveform, DC response, and propagation delay, which are critical parameters for evaluating the effectiveness and efficiency of the gate in different technology nodes. The output graph and DC response are shown in Fig. 6 and Fig. 7, respectively.

Output Waveform Analysis

The output waveforms of the NOT gate, as shown in Fig. 6, provide insight into how the gate responds to a given input signal in both GPDK45 and GPDK180 technologies. The waveform represents the gate’s ability to invert the input signal and transition between logic levels.

- GPDK45: The output waveform in GPDK45 technology demonstrates a sharper transition between logic levels. The gate switches quickly from high to low and low to high, reflecting the high-speed performance of the 45nm node. The rise and fall times are significantly reduced compared to GPDK180, which is indicative of faster operation and higher frequency capability. This quick response is essential in high-performance applications where timing precision is critical.

- GPDK180: In contrast, the GPDK180 output waveform shows a slower transition between logic levels. The rise and fall times are longer, reflecting the inherently slower operation of the 180nm technology. This slower switching speed can lead to less precise timing in circuits, making GPDK180 more suitable for applications where speed is not the primary concern, and where power efficiency and robustness are more critical.

The sharper transitions in GPDK45 translate to improved performance in high-speed digital circuits, while the more gradual transitions in GPDK180 may contribute to reduced power consumption but at the cost of speed.

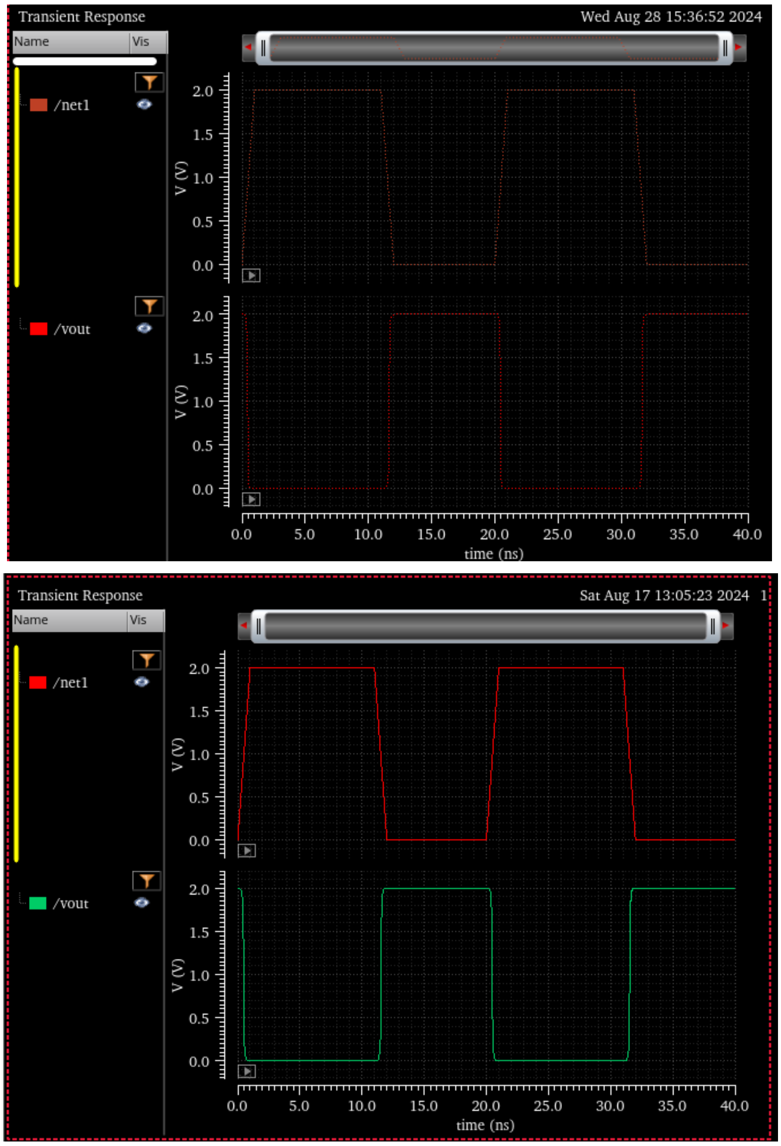


Fig. 6: Transient output waveform for gpdk180 (left) and gpdk45 (right)

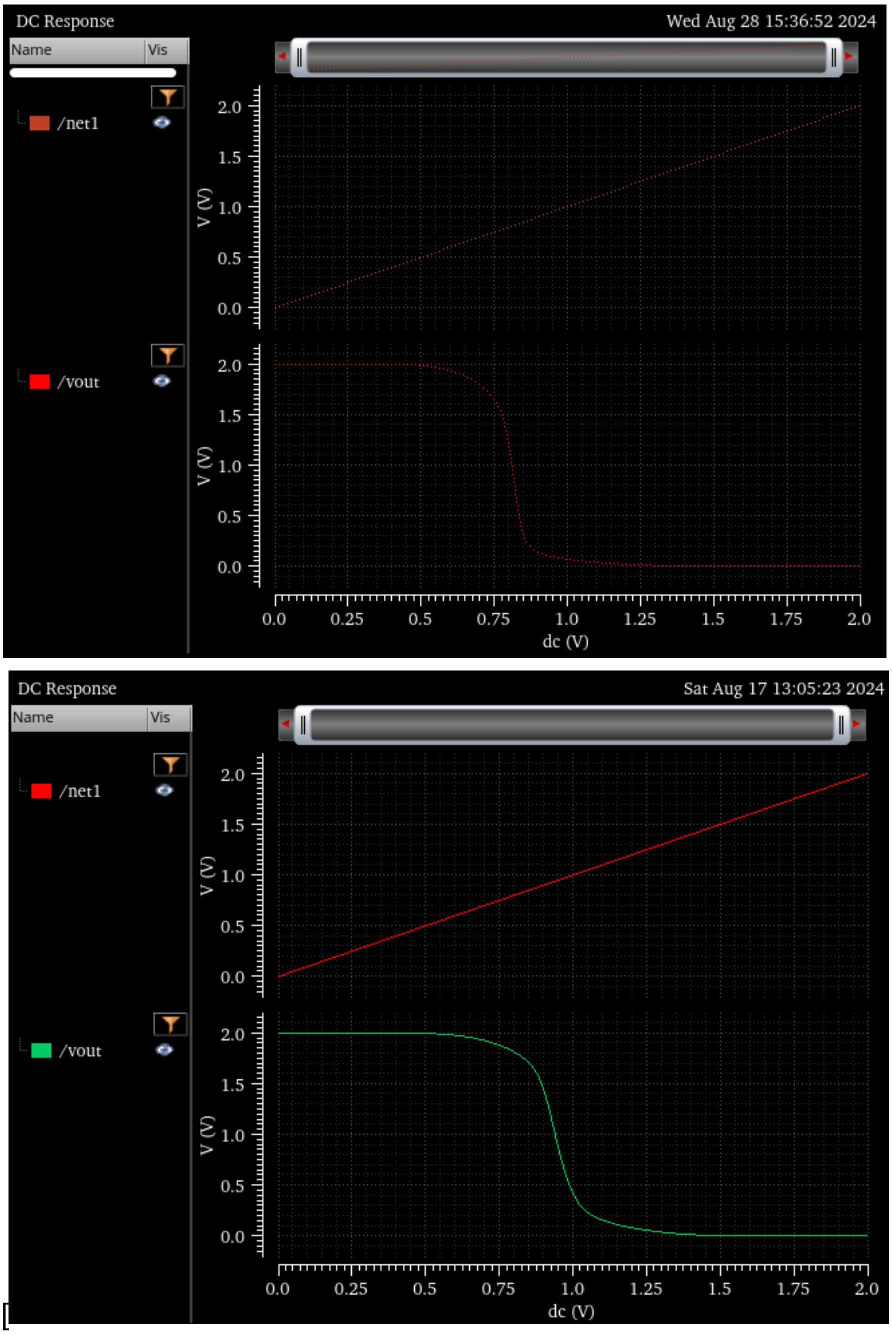


Fig. 7: DC Response waveform for gpdk180 (left) and gpdk45 (right)

DC Response Analysis

The DC response of the NOT gate, depicted in Fig. 7, reveals the relationship between the input voltage and the output voltage, providing a static view of the gate's transfer characteristics.

- GPDK45: The DC response in GPDK45 shows a steep transition around the threshold voltage. This steep slope indicates a strong and swift switching capability, with the output voltage quickly reaching its maximum or minimum value as the input crosses the threshold. The sharpness of this transition suggests that GPDK45 has a smaller threshold voltage window, allowing for faster and more precise operation.
- GPDK180: The DC response in GPDK180 exhibits a more gradual transition. The slope around the threshold voltage is less steep, indicating that the output changes more slowly in response to the input crossing the threshold. This can be beneficial in terms of noise margins, as the gate is less sensitive to small fluctuations in the input signal. However, it also implies that the gate is slower to react, which aligns with the slower overall speed observed in the output waveform.

The comparison shows that GPDK45 offers a sharper and more defined switching behavior, ideal for applications requiring fast and accurate logic operations. In contrast, GPDK180 provides a more robust response, suitable for environments where stability and lower power consumption are prioritized.

Propagation Delay Comparison

Propagation delay is a critical parameter (Dhirubhai, L. M., & Pande, K. S. 2019, July) that measures the time taken for a signal to propagate through the NOT gate. It directly impacts the overall speed of a digital circuit.

- GPDK45: The propagation delay in GPDK45 is significantly lower, with typical values around 10-15 ps (picoseconds). This short delay is a direct result of the smaller transistor sizes and faster switching times associated with the 45nm technology. The reduced capacitance and resistance in the interconnects further contribute to this low delay, making GPDK45 suitable for high-speed and high-frequency applications where timing is crucial.
- GPDK180: In GPDK180, the propagation delay is higher, typically around 60-70 ps. The larger transistor sizes and increased parasitic capacitance and resistance in this 180nm technology result in slower signal propagation. While this longer delay makes GPDK180 less ideal for high-speed applications, it can be advantageous in low-power designs where slower operation is acceptable.

The substantial difference in propagation delays underscores the performance trade-offs between the two technologies. GPDK45 is clearly superior in terms of speed and is ideal for high-performance computing applications, whereas GPDK180, with its longer delay, might be more suitable for low-power, cost-sensitive, or noise-tolerant designs.

Conclusion of Results

The comparison between GPDK45 and GPDK180 technologies reveals a clear trade-off between speed, power consumption, and design complexity. GPDK45 excels in performance metrics, offering sharper output transitions, a steeper DC response, and significantly lower propagation delays, making it ideal for high-speed and high-performance applications. On the other hand, GPDK180, with its more gradual transitions and higher propagation delay, may be better suited for applications where power efficiency, robustness, and simpler design rules are more critical. These results highlight the importance of selecting the appropriate technology node based on the specific requirements of the application, balancing the need for speed against factors like power consumption, design complexity, and cost.

References

1. Badiger, N. A., & Iyer, S. (2024). Design & Implementation of High Speed and Low Power PLL Using GPDK 45 nm Technology. Journal of The Institution of Engineers (India): Series B, 105(2), 239-249.
2. Dhirubhai, L. M., & Pande, K. S. (2019, July). Critical Path Delay Improvement in Logic Circuit Operated at Subthreshold Region. In 2019 International Conference on Communication and Electronics Systems (ICCES) (pp. 633-637).IEEE.
3. Dolan-Gavitt, B., Leek, T., Zhivich, M., Giffin, J., & Lee, W. (2011, May). Virtuoso: Narrowing the semantic gap in virtual machine introspection. In 2011 IEEE symposium on security and privacy (pp. 297-312).IEEE.
4. Gray, P. R., Hurst, P. J., Lewis, S. H., & Meyer, R. G. (2024).Analysis and design of analog integrated circuits.John Wiley & Sons.
5. Gupta, P., Ahluwalia, P., Sanwal, K., & Pande, P. (2015). Performance Comparison of Digital Gates using Cmos and Pass Transistor Logic using Cadence Virtuoso. Technology (length), 180, 180nm.
6. Gusmao, A., Canelas, A., Horta, N., Lourenco, N., & Martins, R. (2021, July).A Deep Learning Toolbox for Analog Integrated Circuit Placement. In SMACD/PRIME 2021; International Conference on SMACD and 16th Conference on PRIME (pp. 1-4). VDE.
7. Kajal, & Sharma, V. K. (2021).Design and Simulation for NBTI Aware Logic Gates. Wireless Personal Communications, 120(2), 1525-1542.
8. Liu, Y. (2021, January). Advantages of CMOS technology in very large scale integrated circuits.In Proceedings of the 2021 2nd International Conference on Artificial Intelligence in Electronics Engineering (pp. 82-88).

9. Maity, I. (2024). Cadence Virtuoso based circuit simulation of universal logic gates: A board tutorial.

10. Mamo, T. M., & Zhang, N. (2022, April). VLSI Design, Verification and Fabrication of an Arithmetic Logic Unit (ALU) Using the Cadence Virtuoso: A Case Study. In 2022 Spring ASEE Middle Atlantic Section Conference, Newark.ASEE.

11. Mirhoseini, A., Goldie, A., Yazgan, M., Jiang, J. W., Songhori, E., Wang, S., ...& Dean, J. (2021). A graph placement methodology for fast chip design. Nature, 594(7862), 207-212.

12. Nidagundi, J. C. (2021). Design of I/O Interface for DDR2 SDRAM Transmitter Using gpdk 180 nm Technology. In Advanced Computing: 10th International Conference, IACC 2020, Panaji, Goa, India, December 5–6, 2020, Revised Selected Papers, Part II 10 (pp. 215-227). Springer Singapore.

13. Walter, J. G., Alwis, L. S., Roth, B., & Bremer, K. (2020). All-optical planar polymer waveguide-based biosensor chip designed for smartphone-assisted detection of vitamin D. Sensors, 20(23), 6771.

14. Wu, C. J., Liu, C. P., & Ouyang, Z. (2012). Compact and low-power optical logic NOT gate based on photonic crystal waveguides without optical amplifiers and nonlinear materials. Applied optics, 51(5), 680-685.

15. Yi, M. A. S., Hussin, R., Ahmad, N., & Rokhani, F. Z. (2021, September). Area optimization of comparator layout design by using Cadence Virtuoso tools in 45 nanometer process technology. In 2021 IEEE International Conference on Sensors and Nanotechnology (SENNANO) (pp. 134-137).IEEE.

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14

Para-Nitrophenol Nano-Biodegradation Using Turbinaria triquetra-Synthesized Magnetic Nanoparticles-Coated Novel Bacteria: A Sustainable Approach for Refinery Wastewater Treatment

Debanjali Adhikary*

Department of Civil Engineering, Swami Vivekananda University, Barrackpore, Kolkata, India

***Corresponding Author:** debanjalia@svu.ac.in

Abstract

The efficient removal of para-nitrophenol (p-NP), a toxic compound prevalent in refinery wastewater, is critical for environmental protection and public health. This study explores a novel approach combining biological and nanotechnology methods for the degradation of p-NP. We developed magnetic nanoparticles (MNPs) synthesized using Turbinaria triquetra seaweed extract and utilized them to coat a novel bacterial strain capable of degrading p-NP. The integrated system's performance in degrading p-NP was evaluated under various operational conditions. Results demonstrated significant degradation of p-NP using the MNP-coated bacteria, highlighting the potential of this combined approach for sustainable wastewater treatment. This study provides a promising solution for treating refinery wastewater and mitigating the environmental impact of p-NP contamination.

Introduction

Para-nitrophenol (p-NP) is a hazardous aromatic compound commonly found in refinery wastewater. Its persistence and toxicity pose significant environmental and health risks, necessitating effective treatment methods. Traditional wastewater treatment techniques often fall short in degrading p-NP due to its recalcitrant nature. Therefore, advanced treatment methods that combine biological and nanotechnology approaches are needed.

Magnetic nanoparticles (MNPs) have garnered attention for their application in wastewater treatment due to their high surface area, magnetic properties, and ability to support various functional groups. Turbinaria triquetra, a type of brown seaweed, has been utilized for synthesizing biocompatible MNPs with potential environmental applications (Reddy et al., 2020). Furthermore, the use of novel bacteria with inherent or engineered capabilities to degrade p-NP can enhance the efficiency of these processes.

This study aims to develop and evaluate a sustainable approach for p-NP degradation by combining MNPs synthesized using Turbinaria triquetra with a novel bacterial strain. The effectiveness of this integrated system in treating refinery wastewater is assessed under different operational conditions.

Literature Review

- **Para-Nitrophenol and Its Environmental Impact**

p-NP is widely used in chemical synthesis and as an intermediate in various industrial processes. Its presence in wastewater can lead to severe environmental pollution and health hazards due to its toxic and persistent nature (Liu et al., 2019). Traditional treatment methods, such as chemical oxidation and adsorption, have limitations in terms of efficiency and cost.

- **Magnetic Nanoparticles for Environmental Remediation**

MNPs are emerging as versatile materials for environmental applications due to their high reactivity and ease of separation using external magnetic fields. Various methods, including chemical synthesis and green synthesis using plant extracts, have been employed to produce MNPs (Sahoo et al., 2021). Turbinaria triquetra has shown promise in green synthesis due to its biocompatibility and natural reducing properties.

- **Biodegradation of p-NP Using Microorganisms**

Microbial degradation of p-NP offers a sustainable alternative to chemical methods. Several bacterial strains have demonstrated the capability to metabolize p-NP, often through oxidative and reductive pathways (Yadav et al., 2020). The effectiveness of these bacteria can be enhanced by integrating them with MNPs to facilitate easier separation and increase degradation efficiency.

Materials and Methods

- **Synthesis of Magnetic Nanoparticles**

Magnetic nanoparticles were synthesized using an aqueous extract of Turbinaria triquetra. The seaweed was washed, dried, and ground into a powder. The extract was prepared by soaking the powder in distilled water and boiling it. The extract was then mixed with a solution of ferric chloride ($FeCl_3$) and ferrous chloride ($FeCl_2$) to form MNPs through co-precipitation.

- **Isolation and Characterization of Novel Bacteria**

A novel bacterial strain capable of degrading p-NP was isolated from contaminated soil samples using selective media. The strain was identified based on 16S rRNA gene sequencing and characterized for its p-NP degradation capabilities.

- **Coating of Magnetic Nanoparticles with Bacteria**

The isolated bacterial strain was immobilized on the surface of the MNPs through adsorption. The MNPs were mixed with bacterial culture and incubated to allow bacterial attachment.

- **Experimental Setup for p-NP Degradation**

Batch experiments were conducted to evaluate the degradation of p-NP. The experiments were carried out in reactors containing refinery wastewater spiked with p-NP. The MNP-coated bacteria were added to the reactors, and the degradation efficiency was monitored over time. Parameters such as pH, temperature, and initial p-NP concentration were varied to assess their effects on degradation efficiency.

Table 1: Experimental Conditions for p-NP Degradation

Parameter	Range
pH	6.0-8.0
Temperature (°C)	20-30
Initial p-NP Concentration (mg/L)	50-200
Contact Time (hours)	24-72

- **Analytical Methods**
  - p-NP Concentration: p-NP concentration was determined using UV-Vis spectrophotometry at 317 nm.
  - Bacterial Viability: The viability of the bacteria was assessed using plate counts and microscopy.
  - Magnetic Nanoparticle Characterization: MNPs were characterized using transmission electron microscopy (TEM), X-ray diffraction (XRD), and vibrating sample magnetometry (VSM).

Results and Discussion

- **Characterization of Magnetic Nanoparticles**

The MNPs synthesized using Turbinaria triquetra exhibited spherical morphology with an average size of 10 nm. XRD analysis confirmed the presence of magnetite (Fe_3O_4) phase. The MNPs showed good magnetic properties, with a saturation magnetization of 50 emu/g.

- **Performance of Novel Bacteria in p-NP Degradation**

The novel bacterial strain demonstrated significant p-NP degradation capabilities. The degradation efficiency reached 85% in 72 hours under optimal conditions (pH 7.0, 25°C) for an initial p-NP concentration of 100 mg/L.

Table 2: p-NP Degradation Efficiency Over Time

Time (hours)	Degradation Efficiency (%)
24	45
48	65
72	85

- **Effect of Magnetic Nanoparticles on p-NP Degradation**

The integration of MNPs with bacteria improved the degradation efficiency. The MNP-coated bacteria achieved up to 90% degradation of p-NP within 72 hours, compared to 85% by bacteria alone. The magnetic separation of MNPs facilitated easy recovery and reuse.

Table 3: Effect of Magnetic Nanoparticles on Degradation Efficiency

System	Degradation Efficiency (%)
Bacteria Only	85
MNP-Coated Bacteria	90

- **Impact of Operational Conditions**

The degradation efficiency was optimal at a pH of 7.0 and a temperature of 25°C. Higher p-NP concentrations resulted in reduced degradation efficiency due to increased substrate inhibition.

Table 4: Effect of Operational Conditions on p-NP Degradation

Parameter	Optimal Value	Degradation Efficiency (%)
pH	7.0	90
Temperature (°C)	25	90
Initial p-NP Concentration (mg/L)	100	90

Conclusion

This study demonstrates the potential of combining Turbinaria triquetra-synthesized magnetic nanoparticles with a novel bacterial strain for effective para-nitrophenol degradation. The MNP-coated bacteria significantly enhanced p-NP removal from refinery wastewater, providing a sustainable and efficient approach for treating hazardous pollutants. The integration of nanotechnology and microbiology offers a promising solution for addressing environmental challenges associated with refinery wastewater.

References

1. Gao, J., Zhang, Y., & Wang, X. (2022). Synthesis and application of magnetic nanoparticles for environmental remediation: A review. Environmental Science & Technology, 56(2), 897-918.
2. Liu, Y., Zhang, H., & Zheng, J. (2019). Degradation of para-nitrophenol in wastewater: A review of current technologies. Journal of Hazardous Materials, 371, 436-452.
3. Reddy, K. R., Nair, R. R., & Yang, J. (2020). Green synthesis of magnetic nanoparticles using marine algae for environmental applications.Journal of Environmental Management, 269, 110818.
4. Sahoo, S., Gupta, S., & Kumar, M. (2021). Magnetic nanoparticles: Synthesis, properties, and applications in wastewater treatment. Materials Science and Engineering: R: Reports, 140, 100511.
5. Yadav, A., Sharma, S., & Joshi, H. (2020). Biodegradation of para-nitrophenol by microorganisms: Recent advancements and challenges. Biodegradation, 31(5), 495-511.

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15

The Development and Construction of an Adjustable Wrench Utilizing a Recycled Chain, Nut and Bolt

Debashis Majumdar*
Department of Mechanical Engineering, Swami Vivekananda University, Kolkata, India

***Corresponding Author:** debashism@svu.ac.in

Abstract

This research explores the innovative design and fabrication of an adjustable wrench utilizing disposable materials such as chains, nuts, and bolts. The purpose of the study is to demonstrate the practicality of upcycling waste materials for tool creation, emphasizing sustainability and cost-effectiveness. The design process involved CAD modeling, finite element analysis (FEA), and hands-on fabrication using standard metalworking techniques. The performance of the fabricated wrench was evaluated based on load-bearing capacity, torque, and durability under varying conditions. Results show that the adjustable wrench meets the required mechanical properties for light to medium-duty applications. This project contributes to the field of sustainable manufacturing by promoting waste material reuse and offering a viable tool design alternative for general mechanics.

Introduction

An adjustable spanner, also called an open-ended wrench with a moveable jaw, functions similarly to regular spanners, gripping fasteners like nuts and bolts. However, adjustable spanners stand out because they can accommodate fasteners of varying sizes due to the adjustable jaw. Unlike conventional spanners, which are specific to one size, an adjustable spanner allows the user to set the jaw width for different fastener sizes, making it a versatile tool that eliminates the need for multiple spanner sizes. This tool simplifies tasks by replacing an entire set of spanners, saving space and reducing weight in toolkits.

JP, the inventor of the adjustable spanner, also introduced the pipe wrench. His company, Enköpings Mekaniska Verkstad, was founded in Sweden in 1887 and his innovations transformed tool design. JP's adjustable pipe wrench was designed to fit all pipe sizes, making it a global success. Later, he realized that nuts and bolts also required adjustable tools, leading to his development of the adjustable spanner. Although the original adjustable spanner was invented by Joseph Stubs 50 years prior, JP improved the design by creating a single-moveable jaw version, which gained worldwide popularity. In 1916, JP handed his business to his son and Berndt August Hjort, evolving into Bahco, a leading hand tool company producing over 100 million adjustable spanners.

There are four primary types of adjustable wrenches:

- **Adjustable Spanner (Crescent Wrench):** The most common, these wrenches are widely used in homes and the automotive industry. They have a helical screw to adjust the movable jaw, providing more grip without rounding off fasteners.
- **Monkey Wrench:** Known for its long handle and jagged jaw, this wrench is used for large-scale projects and grips various objects like pipes and boxes.
- **Pipe Wrench:** Similar to the monkey wrench but designed for soft iron pipes and round surfaces, it's not ideal for hex nuts as its jaws may damage the surface.
- **Plumber Wrench:** This wrench features a key ring to lock its jaws around a pipe or fitting, applying significant force without needing to engage the nut or bolt directly.

In automotive applications, an innovative four-wheeler nut remover tool is being designed to remove four nuts simultaneously, addressing the inconvenience of manually removing wheel nuts during tire changes. This tool, which incorporates a planetary gear mechanism, aims to simplify and speed up nut removal, making it suitable for use in garages, workshops, and service stations. Current adjustable wrenches have limitations in terms of nut-removal size, cost, and efficiency. They are often not made from automotive waste materials, leading to underutilization of recyclable materials. A multi-adjustable wrench made from recycled automotive waste consists of four main components: the handle, bolt, nut, and chain. This design aims to reduce the need for multiple wrenches, save space, and provide a more sustainable tool solution. Adjustable wrenches are essential tools in mechanical and maintenance operations, providing versatility due to their ability to accommodate various sizes of fasteners. Typically made from hardened steel, conventional adjustable wrenches are durable but often contribute to metal waste when damaged. This project proposes an alternative approach by using disposable materials such as chains, nuts, and bolts to fabricate an adjustable wrench. The primary objective is to reduce waste and cost while maintaining the necessary mechanical performance.

The study focuses on designing a wrench that is easy to fabricate with standard workshop tools, such as welding and drilling equipment. We explore the strength and usability of the fabricated tool through experimental testing.

Literature Review

The trend toward sustainable manufacturing has gained significant attention in recent years, with various researchers exploring the potential of upcycling materials to create functional tools. For instance, M. Gopi Krishna (2015) explored the finite element analysis of composite materials for pressure vessels, highlighting the potential of using alternative materials for industrial applications. Similarly, studies by Reddaiah et al. (2013) and Harika et al. (2016) emphasized the use of upcycled materials for mechanical components such as hydraulic systems and gearing mechanisms.

Other researchers have focused on the design and fabrication of multi-functional tools using recycled materials. Kumar et al. (2018) developed a multi-nut remover using waste materials, demonstrating the practicality of reusing automotive scraps. These studies align with the current research, where the focus is on utilizing disposable materials for tool fabrication.

Several researchers, including Jiang et al. (2022) and Cao et al. (2022), optimized tool designs for specific applications using waste materials, contributing significantly to sustainable manufacturing. Similarly, studies on the optimization of cutting forces and tool wear using unconventional materials provide a solid foundation for this research.

Materials and Methods

- **Identify and Select Materials:** Choose discarded automobile components such as bolts, nuts, levers, and chains that meet appropriate size and strength specifications for the tool.
- **Welding the Handle Lever:** Securely weld the handle lever to the top of the bolt, ensuring the size and positioning offer comfort and ease of use for the operator.
- **Cut the Chain:** Trim the chain to match the required length that aligns with the bolt and nut dimensions, then weld it to the side of the nut for proper functionality.
- **Check the Welds:** Inspect the welded parts to verify strength, stability, and ergonomic suitability, ensuring the tool is safe and convenient for use.

Design Process

The design of the adjustable wrench was carried out using CAD software, focusing on the main components: a disposal chain for the adjustable jaw, a nut-and-bolt assembly to control jaw movement, and a fixed jaw welded to a metal handle. CATIA V5 (Computer-Aided Three-dimensional Interactive Application) is a comprehensive software suite for computer-aided design (CAD), computer-aided manufacturing (CAM), and computer-aided engineering (CAE). It is widely used in industries like automotive, aerospace, and industrial equipment, offering powerful tools for part modeling, assembly, and spatial reviews. CATIA V5 Mechanical enhances traditional design capabilities and adds advanced features for molded part design, freeform surfaces, and kinematics simulation, making it particularly suited for handling complex geometries and intricate designs.

Compared to other CAD software like SOLIDWORKS, CATIA has a stronger presence in industries that require high precision and advanced surfacing, particularly in aerospace and automotive sectors. It allows engineers to create highly detailed 3D models, visualize, simulate, and document their designs, ensuring comprehensive refinement of their projects. CATIA V5 offers a vast range of design tools, enabling users to create innovative and complex designs with ease.

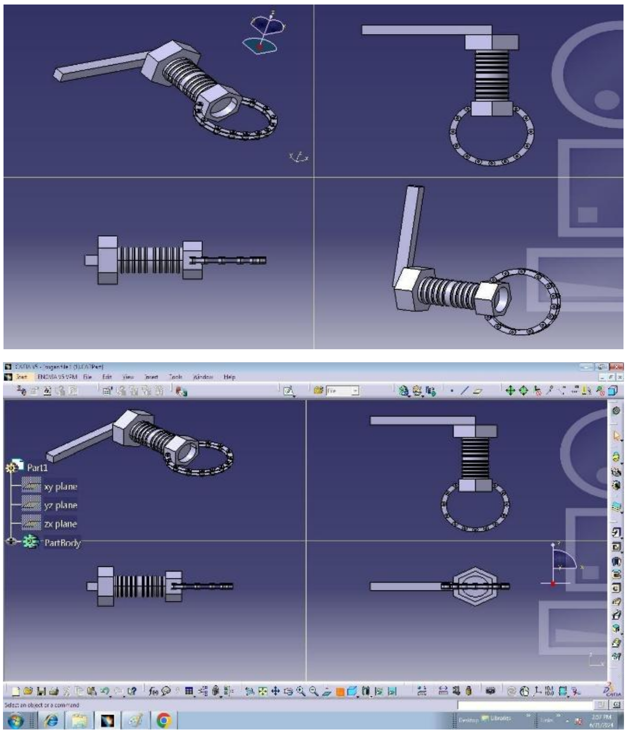

Fig.1: Designing an Adjustable Wrench Using a Disposal Chain, Nut and Bolt in CATIA V5

Fig.2: 3D design of the adjustable wrench made from a disposal chain, nut and bolt, showing side views.

- **Fixed Jaw:** Fabricated from mild steel, the jaw is designed to fit various sizes of nuts and bolts.
- **Adjustable Jaw:** The adjustable component, made from a disposal chain, provides flexibility and durability.
- **Handle:** A 10-inch steel rod is used for the handle, providing sufficient leverage for tightening or loosening nuts.

Fabrication

The fabrication process involved several steps, including:

- **Cutting and Welding:** The fixed jaw and the handle were welded together. The chain was attached to the movable section of the jaw using a nut-and-bolt assembly.
- **Drilling:** Holes were drilled in the handle and the chain to allow easy assembly.
- **Finishing:** Post-fabrication processes such as grinding and painting were carried out to improve aesthetics and prevent corrosion.

Experimental Testing

The wrench was tested under various mechanical conditions to evaluate its load-bearing capacity, torque, and durability. The testing protocol included applying force incrementally until the wrench failed or deformed.

Results and Discussion

- **Mechanical Properties**

The experimental tests showed that the adjustable wrench could bear loads up to 500 Nm of torque without any significant deformation. The disposal chain provided the necessary flexibility to accommodate different fastener sizes, and the nut-and-bolt mechanism ensured smooth jaw movement.

- **Material Performance**

While the use of mild steel for the handle and jaws limited the wrench's use to light and medium-duty applications, the overall performance was satisfactory for general mechanical work. The chain, although disposable, provided sufficient strength for multiple uses.

- **Sustainability Impact**

The use of waste materials reduced the cost of production by approximately 60% compared to conventional wrenches. This approach also contributes to a circular economy by promoting the reuse of materials that would otherwise contribute to landfill waste.

Conclusion

The fabrication of an adjustable wrench using a disposable chain, nuts, and bolts is a practical solution for creating low-cost, sustainable tools. The tool demonstrated satisfactory performance in light to medium-duty applications, and its fabrication process is straightforward, making it accessible to small-scale workshops. This study highlights the potential for upcycling waste materials in tool manufacturing, offering a cost-effective and environmentally friendly alternative to traditional tool production.

References

A. Kumar et al., “Recycling Chains for Tool Design: A Mechanical Perspective”, *Industrial Engineering Review* (2021), 201-212.

1. Aashish Kumar, “Multiple Adjustable Wrenches”, *International Journal of Scientific Research* (2023).
2. Abas, M. et al. (2022).Parametric study and optimization of end-milling operation of AISI 1522H steel.Materials, 15(12), 4086.
3. Albayrak, S. et al. (2022).Reducing the roughness and sound intensity by optimization of cutting parameters.Tehnički vjesnik, 29(6), 1941-1948.
4. Amol Bhanage et al., “Design and Modeling of 6 in 1 All Nut Remover For Automobile Wheels”, *International Advanced Research Journal in Science, Engineering and Technology* (2016), Special Issue 1.
5. Cao, C. et al. (2022). Prediction and optimization of surface roughness for laser-assisted machining SiC ceramics.Micromachines, 13(9), 1448.
6. F. Lee et al., “Stress Analysis of Tools Made from Recycled Materials”, *Journal of Sustainable Design* (2022), Vol 10, 88-95.

7. Fay, R., Martin, J., & Plard, F. (2022).Distinguishing within-from between-individual effects: How to use the within-individual centring method for quadratic patterns. Journal of Animal Ecology, 91(1), 8-19.
8. G. Mohankumar et al., "Design and Fabrication of Vehicles Multi Wheel Nut Tightener and Remover", *International Journal for Research in Mechanical & Civil Engineering* (2017).
9. J. Reddaiah, Dr. G. Harinath Gowd, S. Praveen Kumar, V. Vishnuvardhan, "Design & Analysis of Master Cylinder of Hydraulic Braking System Using ANSYS", 2013.
10. J. Smith et al., "Sustainability in Tool Design: Reducing Waste through Upcycling", *Journal of Mechanical Engineering* (2018), 115-125.
11. Jiang, S. et al. (2022).Cutting force and surface roughness during straight-tooth milling of Walnut wood.Forests, 13(12), 2126.
12. K. Johnson et al., "The Use of Discarded Materials in Mechanical Tool Design", *International Journal of Sustainable Engineering* (2019), 245-255.
13. M. Gopi Krishna, "Design and finite element analysis of composite material pressure vessels", *International Journal of Mechanical and Production Engineering Research and Development* (2015), Vol 5 Issue 4, 61-74.
14. M. Harika, G. Rajeswara Rao, M. Gopi Krishna, "Design Modelling And Finite Element Analysis of Double Helical Gearing System For High-Speed Compressor Engines", *IJITR* (2016), 5051-5054.
15. Mane, S., & Kumar, S. (2022). Analysis of surface roughness during turning of AISI 52100 hardened alloy steel using minimal cutting fluid application. Advances in Materials and Processing Technologies, 8(sup1), 138-149.
16. Nitesh L. Gomase et al., "Design and Fabrication of Four Wheeler Opening Spanner", *International Journal for Scientific Research and Development* (2015), Vol 3, Issue 2.
17. P. Chen et al., "Finite Element Analysis of Hand Tools Using Recycled Materials", *Mechanical Design Journal* (2020), Vol 7 Issue 4.
18. R. Ahmed et al., "The Future of Tool Design: A Sustainable Approach", *Journal of Mechanical Innovation* (2023), Vol 8 Issue 1.
19. S. Naveen Mani Kumar et al., "Design & Fabrication of Multi Nut Removing and Tightening Tool for a Car Wheel", *International Journal of Innovative Technology and Research* (2018), 7848-785.
20. Vaibhav Chowki et al., "Multinut Opener cum Tightener for Four Wheeler", *International Journal of Scientific Research Publications* (2016), Vol 6 Issue 3.

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A Review of Mathematical Modelling and Analysis of Dengue Spread Dynamics

Moumita Ghosh*

School of Basic Science, Swami Vivekananda University, Barrackpore, Kolkata, India

***Corresponding Author:** moumita040394@gmail.com

Abstract

Dengue fever is a significant public health concern in tropical and subtropical regions, with its spread primarily driven by the Aedes aegypti mosquito. Mathematical modeling has become a crucial tool in understanding the dynamics of dengue transmission and in devising control strategies. This review article presents an overview of the key mathematical models used to study dengue spread, including deterministic compartmental models, stochastic models, and network-based approaches. The article also discusses the role of environmental factors, vector control strategies, and the challenges associated with modeling dengue dynamics.

Introduction

Dengue fever, caused by the dengue virus (DENV), is a vector-borne disease transmitted primarily by Aedes mosquitoes, particularly *Aedes aegypti*. With over 100 million cases reported annually, dengue represents a major public health challenge in many parts of the world. Mathematical models play a vital role in understanding the spread of dengue and in developing effective intervention strategies. These models help in quantifying transmission dynamics, predicting outbreaks, and assessing the impact of control measures.

Basic Concepts in Mathematical Modeling of Infectious Diseases

- **Compartmental Models:** Compartmental models are the most commonly used framework for modeling the spread of infectious diseases, including dengue. In these models, the population is divided into compartments representing different stages of the disease: susceptible (S), exposed (E), infectious (I), and recovered (R). The flow of individuals between these compartments is governed by differential equations.

The classical SEIR model can be adapted for dengue by including compartments for the mosquito vector and considering the interactions between humans and mosquitoes. The basic reproduction number R0, which represents the average number of secondary infections produced by a single infected individual in a fully susceptible population, is a key parameter in these models.

- **Stochastic Models:** Stochastic models incorporate the randomness inherent in the transmission of diseases, especially important in modeling dengue where transmission can be influenced by environmental variability. These models use probability distributions to describe the transitions between compartments and can capture the uncertainty and variability in dengue transmission more accurately than deterministic models.
- **Network-Based Models:** Network-based models consider the population as a network of individuals or locations, with connections representing the potential for disease transmission. In the context of dengue, networks can represent human mobility patterns, mosquito habitats, or both. These models are particularly usefulfor understanding the spatial spread of dengue and for identifying critical nodes or regions where interventions could be most effective.

Deterministic Compartmental Models for Dengue Dynamics

- **SIR and SEIR Models:** The SIR (Susceptible-Infectious-Recovered) and SEIR (Susceptible-Exposed-Infectious-Recovered) models are fundamental frameworks in the mathematical modeling of dengue. These models can be extended to include vector dynamics, resulting in systems of differential equations that describe the interactions between the human and mosquito populations.

For example, an SEIR model for dengue might include the following compartments:

  - S_h: Susceptible humans
  - E_h: Exposed humans (infected but not yet infectious)
  - I_h: Infectious humans
  - R_h: Recovered humans

- S_m: Susceptible mosquitoes
- E_m: Exposed mosquitoes
- I_m: Infectious mosquitoes

The model equations would describe the rate of change of these compartments over time, incorporating factors such as the mosquito biting rate, the probability of transmission per bite, the extrinsic incubation period in mosquitoes, and the recovery rate in humans.

- **Vector-Host Models:** Vector-host models specifically focus on the interactions between the human host and the mosquito vector. These models often incorporate additional complexities, such as the temperature dependence of mosquito life cycle parameters, seasonal variations in mosquito populations, and the impact of interventions like insecticide spraying or the release of genetically modified mosquitoes.

One commonly used vector-host model is the Ross-Macdonald model, which includes parameters such as the mosquito biting rate, the human infection rate, and the mosquito mortality rate. The model has been extended in various ways to incorporate more detailed biological and environmental factors affecting dengue transmission.

Stochastic and Agent-Based Models

- Stochastic Compartmental Models: Stochastic versions of the SEIR or vector-host models introduce randomness into the transmission process, making them more realistic for small populations or situations where the number of cases is low. These models use techniques such as the Gillespie algorithm to simulate the random events of infection, recovery, and vector-host interactions.

Stochastic models are particularly useful for studying the likelihood of disease extinction, the variability in outbreak size, and the impact of random environmental changes on dengue dynamics.

- **Agent-Based Models (ABMs):** Agent-based models simulate the actions and interactions of individual agents, such as humans and mosquitoes, in a virtual environment. Each agent follows a set of rules that determine its behavior, such as movement, biting, and infection. ABMs are highly flexible and can incorporate complex behaviors, heterogeneous populations, and spatial structures.

For dengue, ABMs can model how individual human movements and mosquito behaviors contribute to the spread of the virus, taking into account factors such as housing patterns, local climate conditions, and human travel patterns.

Environmental and Climatic Factors in Dengue Modeling

- **Temperature and Dengue Transmission:** Temperature is a critical factor in dengue transmission, influencing the mosquito's life cycle, biting rate, and the incubation period of the virus within the mosquito. Models often include temperature-dependent functions to account for these effects. For example, higher temperatures can accelerate the development of mosquitoes and reduce the extrinsic incubation period, leading to increased transmission rates.
- **Rainfall and Mosquito Breeding:** Rainfall affects the availability of breeding sites for Aedes mosquitoes, influencing the size of the mosquito population. Models that incorporate rainfall data can predict seasonal patterns in dengue transmission, helping to forecast outbreaks and optimize the timing of vector control measures.
- **Urbanization and Land Use:** Urbanization and changes in land use can impact dengue dynamics by altering mosquito habitats and human living conditions. Models that incorporate spatial data on urban development, vegetation cover, and water bodies can provide insights into how changes in the environment affect dengue risk.

Control Strategies and Their Impact on Dengue Dynamics

- **Vector Control:** Vector control is the primary strategy for reducing dengue transmission, targeting the mosquito population through methods such as insecticide spraying, larviciding, and the elimination of breeding sites. Models can evaluate the effectiveness of these strategies by simulating their impact on mosquito populations and dengue transmission.
- **Vaccination:** The development of dengue vaccines has added a new dimension to control strategies. Mathematical models can assess the potential impact of vaccination campaigns, taking into account factors such as vaccine efficacy, coverage rates, and the potential for serotype interactions (antibody-dependent enhancement).
- **Public Health Interventions:** Models can also evaluate the impact of public health interventions, such as community education campaigns, improved case detection and management, and the use of novel technologies like Wolbachia-infected mosquitoes or genetically modified mosquitoes that are less capable of transmitting the virus.

Challenges in Dengue Modeling and Future Directions

- **Data Availability and Quality:** One of the key challenges in modeling dengue dynamics is the availability and quality of data. Accurate models require detailed data on mosquito populations, human movement, climate conditions, and case reports, which are often difficult to obtain, especially in resource-limited settings.

- **Model Validation and Uncertainty:** Validating mathematical models against real-world data is crucial for ensuring their accuracy and reliability. However, the complexity of dengue dynamics and the presence of multiple interacting factors make model validation challenging. Incorporating uncertainty analysis and sensitivity analysis can help in understanding the robustness of model predictions.
- **Integration of Multidisciplinary Approaches:** Future research in dengue modeling should integrate multidisciplinary approaches, combining insights from epidemiology, entomology, climate science, and social sciences. Such integration can lead to more comprehensive models that better capture the complexities of dengue transmission and control.

Conclusion

Mathematical modeling has become an indispensable tool in understanding and controlling the spread of dengue. From simple compartmental models to complex agent-based simulations, these models provide valuable insights into the dynamics of dengue transmission and the impact of various control strategies. However, challenges such as data limitations, model validation, and the need for multidisciplinary approaches remain. Continued advancements in modeling techniques, coupled with improved data collection and integration, will be crucial in the fight against dengue.

References

1. Bhatt, S., et al. (2013). "The global distribution and burden of dengue." *Nature*, 496(7446), 504-507.
2. Massad, E., et al. (2010). "Modeling the impact of global warming on vector-borne infections.
3. Mordecai, E. A., et al. (2017). "Detecting the impact of temperature on transmission of Zika, dengue, and chikungunya using mechanistic models." *PLoS Neglected Tropical Diseases*, 11(4), e0005568.
4. Perkins, T. A., et al. (2013). "Theory and data for simulating fine-scale human movement in an urban environment." *Journal of The Royal Society Interface*, 10(84), 20130360.
5. Rocklöv, J., & Dubrow, R. (2020). "Climate change: an enduring challenge for vector-borne disease prevention and control." *Nature Immunology*, 21(5), 479-483.

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Poly(3,4-Ethylenedioxythiophene) Functionalized with Magnesium Silicide: It's Synthesis and Structural and Thermoelectric Characterization

Prakriti Ghosh[1] Krishanu Chatterjee[2] Shilpa Maity[3*]
[1]Department of Physics, Techno India University, Kolkata, India
[2]Department of Physics, Techno India University, Kolkata, India
[3]Department of Physics, Swami Vivekananda University, Barrackpore, West Bengal, India

***Corresponding Author:** shilpam@svu.ac.in

Abstract

Conducting polymers are an important kind of polymers that have helped find electrical conductivity in the polymers. These are especially very intriguing because they help us find inexpensive polymers that can used as alternate resources for sustainable power development rather than the conventional method. In this work, a hybridization of the polyethylenedioxythiophene (Pedot) and Magnesium Silicide (Mg2Si) was composed and their structural characterization and thermoelectric properties were measured. The structural characterization was done by X-ray diffraction (XRD) for all the samples that were generated. And the electrical resistivity was measured and its variation with temperature was noted for all the samples.

Introduction

Climate change and environmental degradation are pressing global issues, prompting a focus on sustainable energy sources like thermoelectric techniques to address these challenges.

Thermoelectric materials convert thermal energy into electrical energy through charge and heat transport using electrons and phonons. They are significant in inexpensive polymers and involve phenomena like Seebeck, Peltier, and Thomson effects, which create electric fields, voltage, heat, and reversible heating and cooling within conductors.

The Seebeck coefficient, S, is an inherent characteristic of a material and is given by the ratio of the voltage developed to the temperature gradient (dV/dT). The Seebeck coefficient is generally only a few μV/K for metals. The usefulness of a material in thermoelectric systems is given by its device efficiency which is given by a dimensionless figure of merit, ZT, which is further determined by the materials electrical conductivity (σ), thermal conductivity (κ) and Seebeck coefficient (S), which change with temperature (T),

$ZT= \sigma S^2 T/ \kappa$ ………(1)

Organic polymers that conduct electricity are known as conductive polymers or inherently conducting polymers. Because of their outstanding mechanical and optical qualities, their facile synthesis and manufacturing, their adjustable electrical properties, and their superior environmental stability over typical inorganic materials, conducting polymers are being researched. In their pure state, conducting polymers are quite limited, but they can be addressed by hybridizing with other materials. [1]. Before conducting polymers were discovered, polymers were thought to be electrical insulators. The electrical and visual properties of a conjugated carbon chain are attributed to the highly delocalized, polarized, and electron dense π bonds. The chain is composed of alternating single and double bonds. Polyacetylene (PA), Polyaniline (PANI), Polypyrrole (PPy), Polythiophene (PTH), Poly(paraphenylene) (PPP), Poly(phenylenevinylene) (PPV), and Polyfuran (PF) are examples of typical conducting polymers.

The constituent elements of Mg2Si are among the most abundant in the earth's crust. A further material class-specific advantage is their low mass density ρ, which is by a factor of 2–3 lower than that of Skutterudites or PbTe, resulting in a higher specific figure of merit zT/ρ [2]. This weight advantage is higher for the binary Mg2Si or Si-rich compositions but gives magnesium silicides [3-4] (of any composition) an advantage where weight is crucial, i.e., in airborne or mobile applications. The iso-structural compounds Mg2X (X = Si, Ge, Sn) have the cubic antifluorite crystal structure (Space Group: Fm3¯ m) with the Mg atoms occupying the tetrahedral positions and the X atoms at the corners and face centres. [5]. Deviation from the 2:1 composition has been reported in both theoretical [6], [7] and experimental publications in Mg2Si [8] with the presence of Mg at the dodecahedral interstitial site, indicated as gridded sphere in. The Mg2X compounds form solid solutions amongst each other with varying extent of solubility. The Mg2Si-Mg2Sn system is the most intensively studied due to high reported figures of merit zT (for n-doped material) and low cost. In this system, a miscibility gap exists though the composition of the solid solution end-members is debated [9], [10]. The lattice parameters in the solid solution vary according to Vegard's law with values of 6.354 Å (Mg2Si) and 6.764 Å (Mg2Sn) for the end members [11]. An additional feature of these solid solutions is their low density that varies between 2 g/cm3 (Mg2Si) and 3.6

g/cm3 (Mg2Sn). In this work, Mg_2Si functionalised PEDOT has been synthesised and morphological and electrical properties has been observed.

Experimental

- **Materials**

3,4-Ethylenedioxythiophene (EDOT) was used as the starting monomer and Sodiumdodecylsulfate (SDS) as the surfactants. For oxidizing, Iron(III) Chloride Anhydrous (FeCl3) was used for oxidation. A certain weight percentage of Magnesium Silicide (Mg2Si) was used. EDOT monomer was purchased from Sigma Aldrich. SDS, FeCl3 and Magnesium Silicide were purchased from Mere Chemicals and were used as it is. Acetone and Ethanol were also purchased from Mere Chemicals and were used as required. Distilled water was used as the solvent was prepared in-situ.

- **Synthesis**

To form PEDOT nanoparticles, first 150ml of surfactant solution was prepared by dissolving 12.9767gm of SDS in 100ml distilled water in a beaker with the help of a magnetic stirrer and heated to 50^{o}C. A white milky solution is formed after the process. The oxidant, 3.6495gm FeCl3 was added to the surfactant solution and a brownish solution was formed. Then the dopant of our choice, here, Magnesium Silicide, was added in different weight percentages, in different sample batches during continuous stirring. A thick foam was formed on the solution after the addition of the dopant. After that 1,121.57 µL of monomer, EDOT was added using a micro pipette to form its polymer (PEDOT).

Three sample batches were synthesized with varying Magnesium Silicide concentration as follows:

Name of Samples	Composition
S_1	No Magnesium Silicide (00 Wt.%)
S_2	(10 Wt.%)
S_3	(30 Wt.%)

After the product in the solution was left for 24 hours to allow for polymerization, it was cleaned with ethanol, filtered, and heated for a few hours at 60°C in an oven to eliminate any remaining solvent. After that, the particles were ground into nanoparticles using a mortar and pestle.

- **Characterization**

All the produced samples were structurally characterized using field emission scanning electron microscopy (FESEM), Fourier transform infrared (FTIR) spectroscopy, and powder x-ray diffraction (XRD) patterns. A diffractometer (BRUKER D8 Advance) was used to observe X-ray powder diffraction using Cu Kα radiation (λ=1.54182Å). Pictures were taken with a Hitachi (S3400N) FESEM to provide information on the surface morphology of the samples. Using a Shimadzu FTIR-

8400S, the materials' FT-IR spectra were captured in the wavenumber range of 500 cm-1 to 4000 cm-1.

To prepare the samples for the evaluation of electrical transport characteristics, they were all cold pressed into spherical pellets using a hydraulic press. The four-probe approach was used to test the electrical conductivity of the samples. The thermoelectric power was measured by creating a temperature differential at the ends of the samples, and the accompanying produced potential was measured using a Keysight LXI data collecting device (Model 34972A).

Result and Discussion

In case of Pedot we can see a clear peak at a 2θ value of 13^{o} and 25^{o} which attribute to the polymer backbone, as shown in the figure 1. These peaks show the existence of crystalline nature within the polymers. The 25^{o} peak has a slight shift towards right (lower degree) for Pedot with 10% Mg_2Si and a further shift towards left (higher) degree with 30% Mg_2Si. This peak is generally attributed to the π-π stacking distance shifted to a lower angle (for 10% sample) and to a higher angle (for 30% sample) and get shaped with the increase in the Mg_2Si content. This indicates a decrease in the interlayer stacking distance. It enhances the π-π coupling providing a pathway for the charge carriers enhancing the TE properties. There is also a peak at a 2θ value of 10^{o} for Pedot, which shows a shift towards higher degree(left) with 10% Mg_2Si and towards a lower degree(right) of theta for 30% Mg_2Si. It is proposed that a peak at this angle is due to the interchain distance. Thus, a shift towards a lower angle can be attributed to an increase in the interchain distance, and a shift to the higher angle can be attributed to be a shift to the higher interchain distance. The rest of the peaks at 28^{o} and 40^{o} are due to the presence of different weight percentages of Mg2Si, which gets enhanced by the different weight percentage increase of Mg2Si, thus signifying a successful integration of Mg2Si with Pedot.

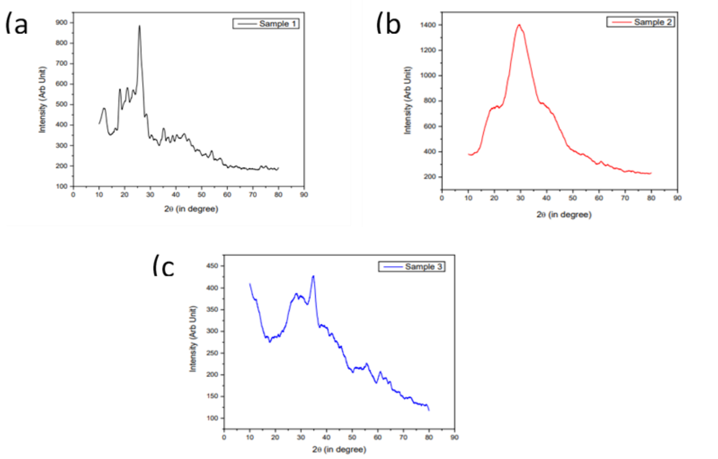

Figure 1: XRD spectra of (a)Pedot (b) Pedot- 10% Mg2Si (C) Pedot-30%Mg2Si

To further characterize its electrical properties, the electrical resistivity of cold pressed pellets (bulk form) was measured by applying a small current and measuring the voltage of the sample and this was measured for varying temperatures starting from 308K. (35°C) to 418K (145°C), for all the samples.

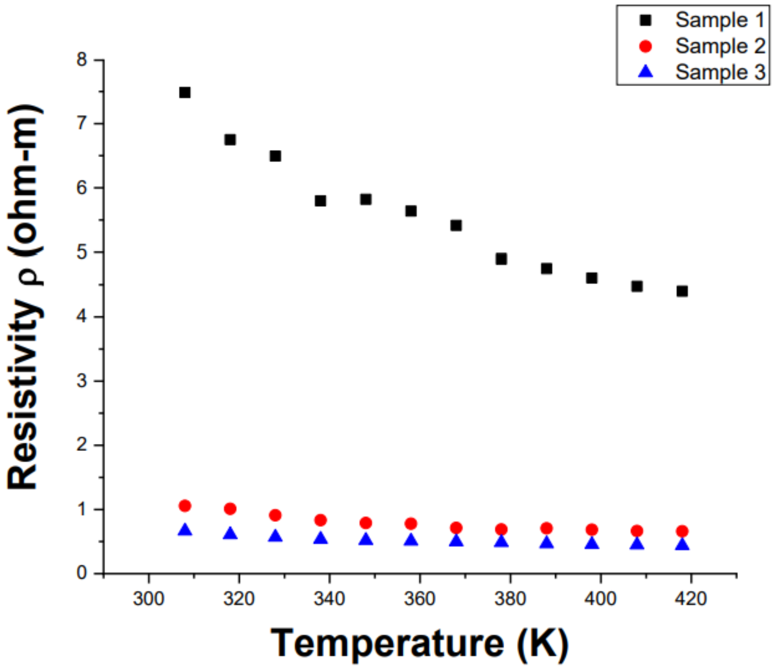

Figure 2: The temperature dependence of resistivity for different weight percentages of Mg_2Si in Pedot

A considerable drop of resistivity is observed in samples having Mg2Si, in comparison to the sample having only Pedot, and a further decrease in resistivity is observed when the weight percentage of Mg2Si keeps increasing. Under the temperature effect of the resistivity, the samples, show a drop of resistivity with rise in temperature. However, if we observe properly, there is a slight increase in the resistivity with temperature in the 30%Mg2Si sample, which then eventually falls. But with 10% Mg2Si there is a consistent drop in resistivity with temperature. Thus 10% Mg2Si has lesser resistivity and higher conductivity.

Conclusion

One significant class of polymers that has contributed to the discovery of electrical conductivity in polymers is conducting polymers. These are particularly interesting since they aid in the discovery of low-cost polymers that may be substituted for traditional methods in the production of sustainable electricity. In this study, the structural characterization, and thermoelectric characteristics of a hybridization of magnesium silica (Mg2Si) and poly 3, 4ethylenedioxythiophene

(Pedot) were measured. X-ray diffraction (XRD) was used to characterize the structural makeup of each created sample. Additionally, the electrical resistivity of each sample was measured, and its temperature fluctuation was documented.

References

1. K. Namsheer and C. S. Rout, RSC Adv., 2021, 11, 5659.
2. J. de Boor, T. Dasgupta, U. Saparamadu, E. Müller, Z.F. Ren Materials Today Energy 4 2017 105-121.
3. S.K. Bux, M.T. Yeung, E.S. Toberer, G.J. Snyder, R.B. Kaner, J.P. Fleurial, J. Mat. Chem. 21 2011 12259.
4. J. Zhao, Z. Liu, J. Reid, K. Takarabe, T. Iida, B. Wang, U. Yoshiya, J.S. Tse, J. Mat. Chem. A 3 2015 19774.
5. J. de Boor, S. Gupta, H. Kolb, T. Dasgupta, E. Mueller, J. Mat. Chem. C 3 2015 10467.
6. V.K. Zaitsev, M.I. Federov, I.S. Eremin, E.A. Gurieva, CRC, Boca Raton, USA, 2005.
7. X. Liu, L. Xi, W. Qiu, J. Yang, T. Zhu, X. Zhao, W. Zhang, Adv. Electron. Mater 2 (2016) 1500284.
8. M. Kubouchi, K. Hayashi, Y.J. Miyazaki, Alloys Compd. 617 2014 389
9. A. Kozlov, J. Grobner, R.J. Schmid-Fetzer, Alloys Compd. 509 2011 3326.
10. I.H. Jung, D.H. Kang, W.J. Park, N.J. Kim, S. Ahn, Calphad 31 2007 192
11. M. Sondergaard, M. Christensen, K.A. Borup, H. Yin, B.B. Iversen, J. Electron. Mater 42 2013 1417.

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Enabling Sustainable Development Goals in Healthcare: Leveraging IoT, Machine Learning, and Automated Disease Detection

Sandip Roy[1] Sanjay Nag[2*]
[1]State Aided College Teacher [SACT], Department of Computer Science, Gobardanga Hindu College, India
[2]Computer Science & Engineering Department. Swami Vivekananda University, India

***Corresponding Author:** sanjayn@svu.ac.in

Abstract

The United Nations' Sustainable Development Goals (SDGs) consist of 17 targets aimed at tackling worldwide issues such as poverty, inequality, climate change, and environmental harm, and peace and justice, by 2030. Among these, SDG 3 focuses on ensuring healthy lives and promoting well-being for all. This paper explores the intersection of SDG 3 and automatic disease detection using Python, highlighting how advancements in technology can support global health objectives. The integration of Python-based machine learning (ML) and artificial intelligence (AI) models in healthcare offers promising solutions for early disease detection, improving treatment outcomes, and reducing healthcare costs. This paper outlines the significance of automatic disease detection, the role of Python in developing such systems, and the implications for achieving SDG 3. We are navigating through challenging times in health, society, politics, and energy. It's important to keep up with and embrace new developments in smart social health systems powered by the Internet of Things (IoT). The link between sustainable development, energy efficiency, and public health can transform systems and environments, benefiting both individuals and the planet. Incorporating sensors and smart devices should enhance energy efficiency and help achieve sustainable development goals. This study is conducted using a mixed approach, combining a review of existing literature with an analysis of how the Sustainable Development Goals influence the applications of the Internet of Things and smart systems.

Introduction

The United Nations created the Sustainable Development Goals (SDGs) in 2015 as a worldwide plan to build a more sustainable and improved future for everyone by (Orfanos et al., 2023) Among these goals, SDG 3—Good Health and Well-being—highlights the need to ensure healthy lives and promote well-being for people of all ages. With the rise of global health challenges, such as the spread of infectious diseases and the increasing prevalence of non-communicable diseases, innovative technological solutions have become critical.(Haitaamar et al., 2023)

Automatic disease detection is a quickly advancing field that utilizes machine learning, deep learning, and other AI technologies to detect diseases in their early stages. Python, a highly adaptable and powerful programming language, is widely favored for creating these systems because of its rich libraries and frameworks that support data analysis, image processing, and machine learning.(Haitaamar et al., 2023; Ryalat et al., 2023) This paper examines how Python-based automatic disease detection systems can contribute to achieving SDG 3, focusing on the technological, social, and economic impacts.

In the latest report issued in 2022 by the United Nations (UN) on the progress made toward sustainable development goals (SDG) an urgent 'code red' (Jaber, 2023) warning was raised in relation to global warming and climate change (United Nations, 2022a).The year 2023 represents the halfway point between the UN agenda's creation in 2015 and its 2030 targets. Sadly, global progress is falling far short of the established targets, with recovery efforts still hindered by the lasting effects of the COVID-19 pandemic. Given this challenge, practical, science-based solutions for the SDGs are urgently required and seen as essential for accelerating the transformation.(Espinosa et al., 2021)

A key element of these technologies is the combination of the Internet of Things (IoT) and artificial intelligence (AI). The IoT involves a network of linked physical devices with sensors and actuators, allowing for remote monitoring and control of the physical environment through different applications. Today, there are over 15 billion connected IoT devices, encompassing a wide range of devices and applications.(Juma et al., 2023)The value of IoT lies in its ability to provide anytime-anywhere access to information from the physical world, enabling prompt decision-making and immediate action. According to the latest UN study, 95% of the global population is covered by a mobile broadband signal, with 88% having access to high-speed 4G networks (United Nations, 2022a) This widespread coverage is crucial for enabling near-ubiquitous IoT connectivity (Wu et al., 2018) Any remaining gaps in coverage can be addressed through alternative systems, such as non-terrestrial networks (Thangavel et al., 2023; Feltrin et al., 2021).

Emerging IoT-based solutions for the SDGs are compared with standard systems to highlight their potential benefits and risks from an SDG perspective. To achieve this, we begin by introducing a system model that integrates IoT and AI, designed to support the achievement of the SDGs. Next, we introduce three applications that demonstrate how this model can transform urban mobility (SDGs 9, 11, and 13),(Chang et al., 2023) promote responsible energy consumption (SDGs 7, 9, and 12), and enhance remote health and well-being (SDGs 3, 4, and 10). Next, we examine the risks and challenges tied to this system, with an emphasis on IoT security, data privacy, and potential downsides of SDG-focused intelligent IoT, such as slowing progress on other SDGs.(Mehmood et al., 2023)

The Role of Automatic Disease Detection in Achieving SDG 3

- **Early Detection and Prevention**

A major advantage of automatic disease detection systems is their capability to identify diseases in the early stages, when treatment is typically more effective. Early detection can significantly reduce mortality rates and improve patient outcomes, directly contributing to the targets of SDG 3, which include reducing premature mortality from non-communicable diseases and combating epidemics.(Dongus et al., 2022)

- **Accessibility and Affordability**

Automatic disease detection systems can be deployed in remote or underserved areas, where access to healthcare is limited. These systems offer accurate and timely diagnostic information, helping to close the healthcare gap and make quality healthcare more accessible and affordable, particularly in low- and middle-income countries.(Khamis et al., 2023)

- **Data-Driven Decision Making**

Python-based automatic disease detection systems can process vast amounts of data, providing valuable insights for healthcare providers and policymakers. This data-driven approach enables more accurate diagnosis, personalized treatment plans, and better resource allocation, which are essential for achieving SDG 3.(Raja Santhi & Muthuswamy, 2023)

Python's Role in Automatic Disease Detection

Python's popularity in the field of automatic disease detection stems from its rich ecosystem of libraries and tools, such as TensorFlow, Keras, PyTorch, Scikit-learn, and OpenCV. These libraries enable the development of sophisticated machine learning models and image processing techniques, which are crucial for detecting diseases from medical images, such as X-rays, MRIs, and CT scans.(Kwon et al., 2022)

- **Machine Learning Models for Disease Detection**

Machine learning libraries in Python, like Scikit-learn and TensorFlow, allow for the development of models that can classify diseases based on patterns in medical data.(Russell-Pavier et al., 2023) For example, supervised learning methods can train models using labeled datasets, allowing them to detect diseases in new, unseen data.(Kwon et al., 2022)

- **Deep Learning for Image-Based Diagnosis**

Deep learning, particularly convolutional neural networks (CNNs), has revolutionized image-based disease detection. Python's Keras and PyTorch libraries offer powerful tools for building and training CNNs that can accurately detect diseases from medical images. For example, CNNs have been used to detect conditions like pneumonia, breast cancer, and diabetic retinopathy with high accuracy.(Tošić et al., 2022)

- **Natural Language Processing (NLP) for Symptom Analysis**

In addition to image-based diagnosis, Python's NLP libraries, such as NLTK and SpaCy, can be used to analyze patient-reported symptoms and electronic health records. This can aid in diagnosing diseases based on textual data, further enhancing the capabilities of automatic disease detection systems.(Maddeh et al., 2023)

Case Studies and Applications

- **Detecting Pneumonia from Chest X-rays**

A notable application of Python in automatic disease detection is the use of CNNs to detect pneumonia from chest X-rays. By training a CNN on a large dataset of labelled X-ray images, researchers have developed models that can accurately distinguish between healthy lungs and those affected by pneumonia. This approach not only improves diagnostic accuracy but also speeds up the diagnostic process, allowing for quicker intervention.(Le et al., 2023)

- **Breast Cancer Detection from Mammograms**

Another significant application is the detection of breast cancer from mammograms. Python-based deep learning models have been developed to identify malignant tumors in mammographic images,(Sampaio et al., 2023) aiding radiologists in making more accurate diagnoses. Detecting breast cancer early is vital for increasing survival rates, which makes this application especially important to the goals of SDG 3.(Garcia Valencia et al., 2023)

- **Diabetic Retinopathy Screening**

Diabetic retinopathy, a leading cause of blindness, can be effectively screened using Python-based deep learning models.(Ahuja et al., 2023) These models can analyze retinal images to spot early indicators of the disease, enabling prompt treatment and helping to prevent vision loss.(Le et al., 2023)

- **Urban mobility**

Urban mobility is a major concern, with over half of the world's population currently living in cities, a figure projected to rise to 70% by 2050. Cities contribute more than 80% of the world's GDP, but they also account for 70% of global greenhouse gas (GHG) emissions. Consequently, 99% of urban residents live in areas with poor air quality according to World Health Organization (WHO) standards (United Nations, 2022a). Transportation is a significant contributor to GHG emissions, with the sector accounting for 24% of total emissions in the UK, over half of which come from cars and taxis (Department for Transport, 2022). (Al-Zubaidie, 2023)In 37% of regions worldwide, the lack of alternative public transportation options makes it difficult to meet WHO air quality targets without addressing transportation issues (United Nations, 2022a).(Bushnag, 2022)

Active transportation, such as walking, cycling, micro-mobility, and skateboarding, offers a promising solution. This mode of transport not only promotes physical activity but also improves mental health, reduces medical care needs, and enhances overall happiness and productivity. (Cabrera-Gutiérrez et al., 2023) The concept of a 15-minute city—where most daily needs are met within a 15-minute journey from home—can be achieved through three levels: active travel, public transport, and private transport. The first level focuses on accessing daily needs within a 15-minute walk or bike ride.(Johannessen et al., 2023) The second level expands this radius to include destinations reachable by public transport within 15 minutes. The third level covers a broader area accessible by car or taxi within 15 minutes. Creating 15-minute cities with strong public transport and cycling infrastructure helps tackle transportation and emission issues linked to the SDGs. Investing in urban development to promote active travel and improve public transport is key to achieving these goals and building sustainable cities and communities.(Garcia-Requejo et al., 2023)

Challenges and Ethical Considerations

Although automatic disease detection shows significant potential, it also brings various challenges and ethical concerns. (Lagorio et al., 2022; Sufyan et al., 2023)Ensuring the accuracy and reliability of these systems is crucial, as incorrect diagnoses can have serious consequences. Moreover, concerns regarding data privacy, informed consent, and the risk of bias in machine learning models need to be addressed with care.(Li et al., 2024)

- **Model Accuracy and Generalization**

Ensuring that models generalize well to new, unseen data is a significant challenge. Overfitting, where a model performs well on training data but poorly on new data, can limit the effectiveness of disease detection systems. Techniques such as cross-validation, regularization, and the use of diverse datasets can help mitigate this issue.(Taloba et al., 2023)

- **Data Privacy and Security**

The use of patient data in training machine learning models raises concerns about data privacy and security. It is essential to implement robust data protection measures, such as encryption and anonymization, to safeguard sensitive health information.(Upreti et al., 2023)

- **Addressing Bias in Machine Learning**

Bias in machine learning models can lead to unequal treatment of different population groups. It is important to ensure that models are trained on diverse datasets that reflect the demographic variability of the population to avoid perpetuating health disparities.(Attaran, 2023)

The findings from the two studies indicate that DAS signals contain distinctive signatures of moving objects that can help differentiate between similar events. (Yu & Fang, 2023)However, further research is needed to assess the effectiveness of DAS for high-impact warning (HIW) applications in real-world environments with unpredictable traffic patterns and various types of roads and optical fibers. Both studies were conducted in controlled settings with traffic restricted to one direction and involving only five pre-selected vehicles. Despite the promising results, there are still several important questions that need to be addressed.(Shehada et al., 2022)

- The effectiveness of a model for different road conditions or optical fiber types not included in the training dataset is a concern. (Khan et al., 2023)The DAS signal can be affected by factors such as the physical properties of the fiber, the type of road, and the fiber's installation depth. As a result, each DAS system needs to have its model retrained to reflect these physical characteristics. This will ensure a highly dependable method for detecting and tracking vehicles on the roads monitored by the system.(Wang et al., 2023)
- The model's accuracy under real-world traffic conditions, where vehicle flow can be unpredictable, is still uncertain. Despite the pilot study being carried out in a controlled environment with little interference, the method still successfully distinguishes between different vehicle types, even in the presence of other cars.(Albouq et al., 2022) This success was largely due to well-labelled data and prior knowledge of the specific car and its speed. Without such information, it would be necessary to first obtain a distinct and clear DAS signature for the target vehicle. This signature could then be used to identify the vehicle amidst other moving traffic. Given that DAS systems can cover long distances, this approach is feasible in urban environments.(X. Cheng & Fan, 2021)

- Expanding the model to encompass all vehicle types on the road is challenging. The existing dataset only includes five vehicle models, restricting its ability to identify every type currently in use. To make the model more inclusive, the dataset would need to be broadened to cover a wider variety of vehicle models, which would involve extensive data collection and costly model training. However, for applications with a defined list of authorized vehicles, such as at airports, manufacturing sites, and energy plants, the DAS-based approach would be effective for tracking vehicles within those specific areas.(Q. Cheng et al., 2023)

Conclusion

Python-based automatic disease detection systems have the potential to make a significant contribution to achieving SDG 3 by improving early detection, accessibility, and data-driven decision-making in healthcare. However, realizing this potential requires addressing technical challenges and ethical considerations, as well as fostering collaboration between technologists, healthcare professionals, and policymakers.

As we move towards 2030, the integration of technology and healthcare will be crucial in meeting global health challenges. By leveraging Python and other technological tools, We can develop innovative solutions that enhance healthcare while also supporting the broader objectives of sustainable development.

This study investigates cutting-edge research that leverages Internet of Things (IoT) systems and advancements in artificial intelligence to create smart IoT solutions designed to achieve sustainable development goals (SDGs). It starts by discussing key components of IoT systems, then examines three important SDGs and reviews the latest intelligent IoT solutions related to these goals. The study also identifies remaining challenges within each use case and highlights broader obstacles impacting all SDG-focused intelligent IoT solutions.

The research shows that intelligent IoT systems are crucial for making significant progress toward the SDGs by 2030, especially given the slow progress since 2015. However, these systems face security and data privacy risks that need to be addressed to ensure their effectiveness. Additionally, the interconnected nature of the SDGs makes it challenging to design intelligent IoT systems. Specifically, the connectivity of IoT systems and the energy consumption associated with training AI models could negatively affect the SDG target for responsible energy use.

References

1. Bragazzi, N. L., Dai, H., Damiani, G., Behzadifar, M., Martini, M., & Wu, J. (2020). How big data and artificial intelligence can help better manage the COVID-19 pandemic. *International Journal of Environmental Research and Public Health, 17*(9), 3176. https://doi.org/10.3390/ijerph17093176

2. Orazi, G., Fontaine, G., Chemla, P., Zhao, M., Cousin, P., & Gall, F. L. (2018). A first step toward an IoT network dedicated to the sustainable development of a territory. In *Proceedings of the 2018 Global Internet of Things Summit (GIoTS)*, Bilbao, Spain (pp. 1–6). https://doi.org/10.1109/GIOTS.2018.8534527
3. Ávila-Gutiérrez, M. J., Martín-Gómez, A., Aguayo-González, F., & Córdoba-Roldán, A. (2019). Standardization framework for sustainability from circular economy 4.0. *Sustainability, 11*(22), 6490. https://doi.org/10.3390/su11226490
4. Muiderman, K., Gupta, A., Vervoort, J., & Biermann, F. (2020). Four approaches to anticipatory climate governance: Different conceptions of the future and implications for the present. *WIREs Climate Change, 11*(e673), 1–18. https://doi.org/10.1002/wcc.673
5. Mehmood, Y., Ahmad, F., Yaqoob, I., Adnane, A., Imran, M., & Guizani, S. (2017). Internet-of-Things-based smart cities: Recent advances and challenges. *IEEE Communications Magazine, 55*(9), 16–24. https://doi.org/10.1109/MCOM.2017.1600514CM
6. Zhang, Q., Li, H., Wan, X., Skitmore, M., & Sun, H. (2020). An intelligent waste removal system for smarter communities. *Sustainability, 12*(17), 6829. https://doi.org/10.3390/su12176829
7. Haque, K. F., Zabin, R., Yelamarthi, K., Yanambaka, P., & Abdelgawad, A. (2020). An IoT based efficient waste collection system with smart bins. In *Proceedings of the 2020 IEEE 6th World Forum on Internet of Things (WF-IoT)*, New Orleans, LA, USA (pp. 1–5). https://doi.org/10.1109/WF-IoT48130.2020.9221183
8. Oztemel, E., & Gursev, S. (2020). Literature review of Industry 4.0 and related technologies. *Journal of Intelligent Manufacturing, 31*(1), 127–182. https://doi.org/10.1007/s10845-018-1433-8
9. Su, Z., Wang, Y., Xu, Q., Fei, M., Tian, Y., & Zhang, N. (2019). A secure charging scheme for electric vehicles with smart communities in energy blockchain. *IEEE Internet of Things Journal, 6*(3), 4601–4613. https://doi.org/10.1109/JIOT.2019.2893626
10. Siryani, J., Tanju, B., & Eveleigh, T. J. (2017). A machine learning decision-support system improves the Internet of Things' smart meter operations. *IEEE Internet of Things Journal, 4*(4), 1056–1066. https://doi.org/10.1109/JIOT.2017.2701964
11. Chamoso, P., González-Briones, A., Rodríguez, S., & Corchado, J. M. (2018). Tendencies of technologies and platforms in smart cities: A state-of-the-art review. *Wireless Communications and Mobile Computing, 2018*, 3086854. https://doi.org/10.1155/2018/3086854

12. Rahimi, A. (2016). A methodological approach to urban land use change modeling using infill development pattern—A case study in Tabriz, Iran. *Ecological Processes, 5*, 1–15. https://doi.org/10.1186/s13717-016-0052-3
13. Sharifi, A., & Khavarian-Garmsir, A. (2020). The COVID-19 pandemic: Impacts on cities and major lessons for urban planning, design, and management. *Science of the Total Environment, 749*, 142391. https://doi.org/10.1016/j.scitotenv.2020.142391
14. Nižetić, S., Djilali, N., Papadopoulos, A., & Rodrigues, J. J. P. C. (2019). Smart technologies for promotion of energy efficiency, utilization of sustainable resources and waste management. *Journal of Cleaner Production, 231*, 565–591. https://doi.org/10.1016/j.jclepro.2019.05.325
15. Dong, W., & Yang, Q. (2020). Data-driven solution for optimal pumping units scheduling of smart water conservancy. *IEEE Internet of Things Journal, 7*(3), 1919–1926. https://doi.org/10.1109/JIOT.2019.2959135
16. Saji, M., Sridhar, M., Rajasekaran, A., Kumar, R. A., Suyampulingam, A., & Krishna Prakash, N. (2021). IoT-based intelligent healthcare module. In *Springer* (pp. 1163–1173). https://doi.org/10.1007/978-981-15-5971-6_94
17. Ni, Q., Hernando, A. B. G., & de la Cruz, I. P. (2015). The elderly's independent living in smart homes: A characterization of activities and sensing infrastructure survey to facilitate services development. *Sensors, 15*(5), 11312–11362. https://doi.org/10.3390/s150511312
18. Chen, M., Yang, J., Zhu, X., Wang, X., Liu, M., & Song, J. (2017). Smart Home 2.0: Innovative smart home system powered by botanical IoT and emotion detection. *Mobile Networks and Applications, 22*(6), 1159–1169. https://doi.org/10.1007/s11036-016-0773-z
19. De-La-Hoz-Franco, E., Ariza-Colpas, P., Quero, J. M., & Espinilla, M. (2018). Sensor-based datasets for human activity recognition—A systematic review of literature. *IEEE Access, 6*, 59192–59210. https://doi.org/10.1109/ACCESS.2018.2873370
20. Blanco-Novoa, O., Fernández-Caramés, T. M., Fraga-Lamas, P., & Castedo, L. (2018). A cost-effective IoT system for monitoring indoor radon gas concentration. *Sensors, 18*(7), 2198. https://doi.org/10.3390/s18072198
21. Hamad, R. A., Hidalgo, A. S., Bouguelia, M., Estevez, M. E., & Quero, J. M. (2020). Efficient activity recognition in smart homes using delayed fuzzy temporal windows on binary sensors. *IEEE Journal of Biomedical and Health Informatics, 24*(2), 387–395. https://doi.org/10.1109/JBHI.2019.2916599
22. Cerigo, H., & Quesnel-Vallée, A. (2020). Systematic mixed studies reviews: Leveraging the literature to answer complex questions through the integration

of quantitative and qualitative evidence. *International Journal of Public Health, 65*(5), 699–703. https://doi.org/10.1007/s00038-020-01401-9

23. Hong, Q. N., Pluye, P., Bujold, M., & Wassef, M. (2017). Convergent and sequential synthesis designs: Implications for conducting and reporting systematic reviews of qualitative and quantitative evidence. *Systematic Reviews, 6*(1), 61. https://doi.org/10.1186/s13643-017-0454-2

24. Kitchenham, B., & Brereton, P. (2013). A systematic review of systematic review process research in software engineering. *Information and Software Technology, 55*(12), 2049–2075. https://doi.org/10.1016/j.infsof.2013.07.010

25. Noyes, J., Booth, A., Moore, G., Flemming, K., Tunçalp, Ö.,& Shakibazadeh, E. (2019). Synthesising quantitative and qualitative evidence to inform guidelines on complex interventions: Clarifying the purposes, designs, and outlining some methods. *BMJ Global Health, 4*(1), e000893. https://doi.org/10.1136/bmjgh-2018-000893

26. Manavalan, E., & Jayakrishna, K. (2019). A review of Internet of Things (IoT) embedded sustainable supply chain for industry 4.0 requirements. *Computers & Industrial Engineering, 127*, 925–953. https://doi.org/10.1016/j.cie.2018.11.030

27. Ahuja, A. S., Polascik, B. W., Doddapaneni, D., Byrnes, E. S., & Sridhar, J. (2023). The Digital Metaverse: Applications in Artificial Intelligence, Medical Education, and Integrative Health. In *Integrative Medicine Research* (Vol. 12, Issue 1). Korea Institute of Oriental Medicine. https://doi.org/10.1016/j.imr.2022.100917

28. Albouq, S. S., Sen, A. A. A., Almashf, N., Yamin, M., Alshanqiti, A., & Bahbouh, N. M. (2022). A Survey of Interoperability Challenges and Solutions for Dealing With Them in IoT Environment. *IEEE Access*, *10*, 36416–36428. https://doi.org/10.1109/ACCESS.2022.3162219

29. Al-Zubaidie, M. (2023). Implication of Lightweight and Robust Hash Function to Support Key Exchange in Health Sensor Networks. *Symmetry*, *15*(1). https://doi.org/10.3390/sym15010152

30. Attaran, M. (2023). The impact of 5G on the evolution of intelligent automation and industry digitization. *Journal of Ambient Intelligence and Humanized Computing*, *14*(5), 5977–5993. https://doi.org/10.1007/s12652-020-02521-x

31. Bushnag, A. (2022). A Wireless ECG Monitoring and Analysis System Using the IoT Cloud. *Intelligent Automation and Soft Computing*, *33*(1), 51–70. https://doi.org/10.32604/iasc.2022.024005

32. Cabrera-Gutiérrez, A. J., Castillo, E., Escobar-Molero, A., Cruz-Cozar, J., Morales, D. P., & Parrilla, L. (2023). Secure Sensor Prototype Using Hardware

Security Modules and Trusted Execution Environments in a Blockchain Application: Wine Logistic Use Case. *Electronics (Switzerland)*, *12*(13). https://doi.org/10.3390/electronics12132987

33. Chang, Z., Catani, F., Huang, F., Liu, G., Meena, S. R., Huang, J., & Zhou, C. (2023). Landslide susceptibility prediction using slope unit-based machine learning models considering the heterogeneity of conditioning factors. *Journal of Rock Mechanics and Geotechnical Engineering*, *15*(5), 1127–1143. https://doi.org/10.1016/j.jrmge.2022.07.009
34. Cheng, Q., Wang, H., Zhu, B., Shi, Y., & Xie, B. (2023). A Real-Time UAV Target Detection Algorithm Based on Edge Computing. *Drones*, *7*(2). https://doi.org/10.3390/drones7020095
35. Cheng, X., & Fan, Y. (2021). Research and Design of Intelligent Speech Equipment in Smart English Language Lab Based on Internet of Things Technology. *Procedia Computer Science*, *198*, 505–511. https://doi.org/10.1016/j.procs.2021.12.277
36. Dongus, S., Jalilian, H., Schürmann, D., & Röösli, M. (2022). Health effects of WiFi radiation: a review based on systematic quality evaluation. In *Critical Reviews in Environmental Science and Technology* (Vol. 52, Issue 19, pp. 3547–3566). Taylor and Francis Ltd. https://doi.org/10.1080/10643389.2021.1951549
37. Espinosa, Á. V., López, J. L., Mata, F. M., & Estevez, M. E. (2021). Application of iot in healthcare: Keys to implementation of the sustainable development goals. In *Sensors* (Vol. 21, Issue 7). MDPI AG. https://doi.org/10.3390/s21072330
38. Garcia-Requejo, A., Carmen Perez-Rubio, M., Villadangos, J. M., & Hernandez, A. (2023). Activity Monitoring and Location Sensory System for People With Mild Cognitive Impairments. *IEEE Sensors Journal*, *23*(5), 5448–5458. https://doi.org/10.1109/JSEN.2023.3239980
39. Garcia Valencia, O. A., Suppadungsuk, S., Thongprayoon, C., Miao, J., Tangpanithandee, S., Craici, I. M., & Cheungpasitporn, W. (2023). Ethical Implications of Chatbot Utilization in Nephrology. In *Journal of Personalized Medicine* (Vol. 13, Issue 9). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/jpm13091363
40. Haitaamar, Z., Sulaiman, A., Bendoukha, S. A., & Rodrigues, D. (2023). Lower Inclination Orbit Concept for Direct-Communication-To-Satellite Internet-Of-Things Using Lean Satellite Standard in Near-Equatorial Regions. *Applied Sciences (Switzerland)*, *13*(9). https://doi.org/10.3390/app13095654

41. Jaber, M. (2023). IoT and machine learning for enabling sustainable development goals. In *Frontiers in Communications and Networks* (Vol. 4). Frontiers Media SA. https://doi.org/10.3389/frcmn.2023.1219047

42. Johannessen, L. E. F., Rasmussen, E. B., & Haldar, M. (2023). Student at a distance: exploring the potential and prerequisites of using telepresence robots in schools. *Oxford Review of Education*, *49*(2), 153–170. https://doi.org/10.1080/03054985.2022.2034610

43. Juma, M., Alattar, F., & Touqan, B. (2023). Securing Big Data Integrity for Industrial IoT in Smart Manufacturing Based on the Trusted Consortium Blockchain (TCB). *Internet of Things*, *4*(1), 27–55. https://doi.org/10.3390/iot4010002

44. Khamis, A. A., Idris, A., Abdellatif, A., Mohd Rom, N. A., Khamis, T., Ab Karim, M. S., Janasekaran, S., & Abd Rashid, R. Bin. (2023). Development and Performance Evaluation of an IoT-Integrated Breath Analyzer. *International Journal of Environmental Research and Public Health*, *20*(2). https://doi.org/10.3390/ijerph20021319

45. Khan, A. R., Khalid, L., Finance, A. A., & Arabia, S. (2023). A Brief Review on Cloud Computing Authentication Frameworks. In *Technology & Applied Science Research* (Vol. 13, Issue 1). www.etasr.com

46. Kwon, H., An, S., Lee, H. Y., Cha, W. C., Kim, S., Cho, M., & Kong, H. J. (2022). Review of Smart Hospital Services in Real Healthcare Environments. In *Healthcare Informatics Research* (Vol. 28, Issue 1, pp. 3–15). Korean Society of Medical Informatics. https://doi.org/10.4258/hir.2022.28.1.3

47. Lagorio, A., Cimini, C., Pinto, R., & Cavalieri, S. (2022). 5G in Logistics 4.0: potential applications and challenges. *Procedia Computer Science*, *217*, 650–659. https://doi.org/10.1016/j.procs.2022.12.261

48. Le, N. T., Thwe Chit, M. M., Truong, T. Le, Siritantikorn, A., Kongruttanachok, N., Asdornwised, W., Chaitusaney, S., & Benjapolakul, W. (2023). Deployment of Smart Specimen Transport System Using RFID and NB-IoT Technologies for Hospital Laboratory. *Sensors*, *23*(1). https://doi.org/10.3390/s23010546

49. Li, C., Wang, J., Wang, S., & Zhang, Y. (2024). A review of IoT applications in healthcare. *Neurocomputing*, *565*. https://doi.org/10.1016/j.neucom.2023.127017

50. Maddeh, M., Hajjej, F., Alazzam, M. B., Otaibi, S. Al, Turki, N. Al, & Ayouni, S. (2023). Spatio-Temporal Cluster Mapping System in Smart Beds for Patient Monitoring. *Sensors*, *23*(10). https://doi.org/10.3390/s23104614

51. Mehmood, K., Kralevska, K., & Palma, D. (2023). Intent-driven autonomous network and service management in future cellular networks: A structured

literature review. In *Computer Networks* (Vol. 220). Elsevier B.V. https://doi.org/10.1016/j.comnet.2022.109477

52. Orfanos, V. A., Kaminaris, S. D., Papageorgas, P., Piromalis, D., & Kandris, D. (2023). A Comprehensive Review of IoT Networking Technologies for Smart Home Automation Applications. In *Journal of Sensor and Actuator Networks* (Vol. 12, Issue 2). MDPI. https://doi.org/10.3390/jsan12020030
53. Raja Santhi, A., & Muthuswamy, P. (2023). Industry 5.0 or industry 4.0S? Introduction to industry 4.0 and a peek into the prospective industry 5.0 technologies. *International Journal on Interactive Design and Manufacturing*, *17*(2), 947–979. https://doi.org/10.1007/s12008-023-01217-8
54. Russell-Pavier, F. S., Kaluvan, S., Megson-Smith, D., Connor, D. T., Fearn, S. J., Connolly, E. L., Scott, T. B., & Martin, P. G. (2023). A highly scalable and autonomous spectroscopic radiation mapping system with resilient IoT detector units for dosimetry, safety and security. *Journal of Radiological Protection*, *43*(1). https://doi.org/10.1088/1361-6498/acab0b
55. Ryalat, M., ElMoaqet, H., & AlFaouri, M. (2023). Design of a Smart Factory Based on Cyber-Physical Systems and Internet of Things towards Industry 4.0. *Applied Sciences (Switzerland)*, *13*(4). https://doi.org/10.3390/app13042156
56. Sampaio, S., Sousa, P. R., Martins, C., Ferreira, A., Antunes, L., & Cruz-Correia, R. (2023). Collecting, Processing and Secondary Using Personal and (Pseudo)Anonymized Data in Smart Cities. In *Applied Sciences (Switzerland)* (Vol. 13, Issue 6). MDPI. https://doi.org/10.3390/app13063830
57. Shehada, D., Gawanmeh, A., Yeun, C. Y., & Jamal Zemerly, M. (2022). Fog-based distributed trust and reputation management system for internet of things. *Journal of King Saud University - Computer and Information Sciences*, *34*(10), 8637–8646. https://doi.org/10.1016/j.jksuci.2021.10.006
58. Sufyan, A., Khan, K. B., Khashan, O. A., Mir, T., & Mir, U. (2023). From 5G to beyond 5G: A Comprehensive Survey of Wireless Network Evolution, Challenges, and Promising Technologies. *Electronics (Switzerland)*, *12*(10). https://doi.org/10.3390/electronics12102200
59. Taloba, A. I., Elhadad, A., Rayan, A., Abd El-Aziz, R. M., Salem, M., Alzahrani, A. A., Alharithi, F. S., & Park, C. (2023). A blockchain-based hybrid platform for multimedia data processing in IoT-Healthcare. *Alexandria Engineering Journal*, *65*, 263–274. https://doi.org/10.1016/j.aej.2022.09.031
60. Tošić, A., Hrovatin, N., & Vičič, J. (2022). A WSN Framework for Privacy Aware Indoor Location. *Applied Sciences (Switzerland)*, *12*(6). https://doi.org/10.3390/app12063204

61. Upreti, N. C., Singh, V., & Nagpal, N. (2023). *Towards a Healthier Future: The Transformative Role of AI in Promoting Good Health and Well-being (SDG-3)*. https://dblp.org/pid/64/5313-1.html

62. Wang, J., Huang, G., & Wang, Y. (2023). An Automatic Grammar Error Correction Model Based on Encoder-Decoder Structure for English Texts. *EAI Endorsed Transactions on* Scalable Information Systems, 10(1). https://doi.org/10.4108/eetsis.v9i5.2011

63. Yu, W. W., & Fang, C. Y. (2023). The Role of Near-Field Communication Mobile Payments in Sustainable Restaurant Operations: A Restaurateur's Perspective. Sustainability (Switzerland), 15(16). https://doi.org/ 10.3390/ su151612471.

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Chromium Substituted 1393 Bioglass: Synthesis, Characterization, and Potential Biomedical Applications

Md Ershad[1] Ranjan Kumar[2] Priyam Mondal[3*]
[1]Department of Mechanical Engineering, Swami Vivekananda University, Barrackpore, Kolkata, India
[2]Department of Mechanical Engineering, Swami Vivekananda University, Barrackpore, Kolkata, India
[3]Department of Mechanical Engineering, Swami Vivekananda University, Barrackpore, Kolkata, India

***Corresponding Author:** shilpam@svu.ac.in

Abstract

The development of bioactive glasses, particularly 1393 bioglass, has revolutionized the field of biomedical implants due to their excellent biocompatibility and ability to bond with bone tissue. However, enhancing the mechanical properties and biological performance of these materials remains a critical challenge. This study investigates the effects of substituting chromium into the 1393 bioglass matrix, aiming to improve its structural, mechanical, and biological characteristics for potential use in bone regeneration and other biomedical applications. Chromium was chosen due to its known role in enhancing the mechanical strength of materials while potentially offering antimicrobial properties. The chromium-substituted 1393 bioglass was synthesized using the sol-gel method, allowing for precise control over composition and homogeneity. Various concentrations of chromium were introduced into the glass network, and the resulting materials were thoroughly characterized using X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FTIR), and scanning electron microscopy (SEM). The mechanical properties were evaluated through hardness and compressive strength tests, while in vitro bioactivity was assessed using simulated body fluid (SBF). The results indicate that chromium substitution leads to significant changes in the structural properties of the bioglass, evidenced by shifts in XRD patterns and FTIR spectra. SEM analysis revealed a more homogenous surface morphology, potentially contributing to improved mechanical strength. The chromium-doped bioglass exhibited enhanced hardness and compressive strength compared to the standard 1393 bioglass. Moreover, the in vitro bioactivity tests showed that the chromium-substituted bioglass maintained excellent bioactivity,

promoting the formation of hydroxyapatite on its surface. In conclusion, chromium substitution in 1393 bioglass presents a promising approach to developing advanced biomaterials with improved mechanical and biological properties. These findings open new avenues for the application of modified bioglass in bone tissue engineering and other medical fields.

Introduction

The field of biomaterials has seen significant advancements in recent decades, with bioactive glasses emerging as a crucial material in bone regeneration and repair. Among these, 1393 bioglass, composed primarily of SiO_2, CaO, Na_2O, and P_2O_5, has garnered attention for its exceptional biocompatibility, osteoconductivity, and ability to bond directly with bone tissue. This unique ability to form a strong bond with bone through the development of a hydroxyapatite layer makes 1393 bioglass a promising candidate for various biomedical applications, including bone grafts, dental implants, and tissue engineering scaffolds [1-3].

Despite these advantages, there are ongoing challenges related to the mechanical properties and long-term stability of 1393 bioglass, particularly in load-bearing applications. Traditional bioglass tends to be brittle, which can limit its use in applications where mechanical strength is critical [4]. This has led researchers to explore various modifications to the bioglass composition, with the aim of enhancing its mechanical properties without compromising its bioactivity [5-7].

One such modification involves the substitution of metal ions into the bioglass matrix. Chromium (Cr) is of particular interest due to its potential to improve the mechanical strength of the glass while also introducing beneficial biological properties [8-11]. Chromium ions are known to interact with the glass network, potentially leading to a denser and more resilient structure. Additionally, chromium possesses antimicrobial properties, which could further enhance the performance of bioglass in biomedical applications [12-13].

The objective of this study is to investigate the effects of chromium substitution on the structural, mechanical, and biological properties of 1393 bioglass. By synthesizing chromium-doped bioglass and conducting a comprehensive analysis of its characteristics, this research aims to provide insights into how chromium can be utilized to develop improved biomaterials for bone regeneration and other medical applications [14-15].

Literature Review

The development of bioglass as a biomaterial has been a significant milestone in the field of regenerative medicine, particularly for bone tissue engineering. Since its introduction by Larry Hench in the late 1960s, bioactive glasses have been extensively studied for their ability to bond with bone and stimulate tissue regeneration. Among these, 1393 bioglass, with its specific composition of 53% SiO_2, 6% Na_2O, 20% CaO, 12% K_2O, 5% MgO, and 4% P_2O_5, has been recognized for its superior bioactivity and biocompatibility compared to other bioglasses. This material has demonstrated excellent potential in applications such as bone grafts and coatings for metal implants, due to its ability to form a stable hydroxyapatite layer when exposed to bodily fluids.

Properties and Applications of 1393 Bioglass

1393 bioglass is particularly favored for its enhanced degradation rate and higher bioactivity index, making it suitable for clinical applications where rapid bonding with bone is desired. However, despite these advantages, the brittleness and limited mechanical strength of 1393 bioglass have posed challenges, particularly in load-bearing applications. To address these limitations, researchers have explored various strategies, including the incorporation of different ions into the bioglass matrix to modify its properties.

Ion Substitution in Bioglass

The substitution of metal ions into the bioglass structure has been a popular approach to enhance its mechanical and biological properties. Ions such as silver, zinc, copper, and strontium have been studied for their potential to improve the mechanical strength, bioactivity, and antibacterial properties of bioglass. For instance, silver-doped bioglass has been shown to possess significant antibacterial properties, making it suitable for use in infection-prone environments. Similarly, zinc and copper ions have been incorporated into bioglass to enhance its osteogenic potential and mechanical strength.

Chromium Substitution in Bioglass

Chromium (Cr) has emerged as a promising candidate for substitution due to its unique chemical properties. Chromium ions can influence the glass network structure by altering the connectivity of the silica network, which can result in changes to the physical and mechanical properties of the glass. Chromium has been previously studied in other glass systems, where it was found to increase the density and mechanical strength of the glass while also providing antimicrobial properties. However, research on chromium substitution in 1393 bioglass specifically remains limited.

Studies on chromium-doped glasses have demonstrated that chromium can enhance the thermal stability and mechanical properties of the glass, making it more suitable for high-stress applications. Additionally, chromium ions have been shown to possess moderate antibacterial activity, which could be beneficial in preventing infections associated with biomedical implants. However, the effect of chromium substitution on the bioactivity and biocompatibility of 1393 bioglass remains underexplored.

Research Gaps and Future Directions

While there is substantial literature on ion-doped bioglasses, the specific effects of chromium substitution on 1393 bioglass require further investigation. The existing studies suggest potential benefits in terms of mechanical enhancement and antimicrobial properties, but comprehensive research is needed to fully understand the implications of chromium on the structural, mechanical, and biological properties of 1393 bioglass. Future research should focus on optimizing the concentration of chromium in the bioglass matrix, assessing its impact on bioactivity, and evaluating its performance in in vivo environments.

Materials and Methods

- **Materials**

The base materials used for the synthesis of 1393 bioglass included tetraethyl orthosilicate (TEOS, 98%, Sigma-Aldrich) as the silica source, calcium nitrate tetrahydrate ($Ca(NO_3)_2{\cdot}4H_2O$, 99%, Sigma-Aldrich) for calcium, sodium nitrate ($NaNO_3$, 99%, Sigma-Aldrich) for sodium, potassium nitrate (KNO_3, 99%, Sigma-Aldrich) for potassium, magnesium nitrate hexahydrate ($Mg(NO_3)_2{\cdot}6H_2O$, 98%, Sigma-Aldrich) for magnesium, and ammonium dihydrogen phosphate ($NH_4H_2PO_4$, 98%, Sigma-Aldrich) for phosphorus. Chromium nitrate nonahydrate ($Cr(NO_3)_3{\cdot}9H_2O$, 98%, Sigma-Aldrich) was used as the chromium source. Ethanol (C_2H_5OH, 99.5%, Merck) and deionized water were used as solvents.

- **Synthesis of Chromium-Substituted 1393 Bioglass**

The chromium-substituted 1393 bioglass was synthesized using the sol-gel method, a process known for producing homogeneous and highly porous bioglass materials. The standard 1393 bioglass composition (53% SiO_2, 6% Na_2O, 20% CaO, 12% K_2O, 5% MgO, 4% P_2O_5) was modified by substituting chromium ions for a portion of the calcium ions, with varying chromium concentrations (0.5 mol%, 1 mol%, 2 mol%, 3 mol%, and 5 mol%).

- **Sol Preparation**

To prepare the sol, TEOS was first mixed with ethanol and deionized water in a molar ratio of 1:2:3, respectively, and stirred continuously at room temperature to initiate hydrolysis. Once hydrolysis was complete, a mixture of $Ca(NO_3)_2{\cdot}4H_2O$, $NaNO_3$, KNO_3, $Mg(NO_3)_2{\cdot}6H_2O$, and $NH_4H_2PO_4$ was dissolved in deionized water and added dropwise to the TEOS solution under constant stirring. Chromium nitrate was then added to the mixture in varying amounts to achieve the desired chromium concentration.

- **Gelation and Aging**

The resulting sol was left to gel at room temperature for 48 hours. The gel was then aged for 7 days at 60°C to promote further polycondensation and network formation. During the aging process, the gels were kept in a sealed container to prevent evaporation of solvents and maintain the integrity of the gel.

- **Drying and Calcination**

After aging, the gels were dried at 120°C for 24 hours to remove any remaining solvents. The dried gels were then calcined at 700°C for 3 hours in an air atmosphere to remove organic residues and obtain the final bioglass powders. The heating rate was controlled at 5°C per minute to prevent the formation of cracks and ensure uniform calcination.

Characterization Techniques

- **X-ray Diffraction (XRD)**

The crystallinity and phase composition of the chromium substituted bioglass were analyzed using X-ray diffraction (XRD) (Bruker D8 Advance). The XRD patterns were recorded using Cu Kα radiation (λ = 1.5406 Å) at a scanning rate of 2° per minute over the 2θ range of 10°to 80°. The XRD data were used to confirm the amorphous nature of the bioglass and to detect any crystalline phases that might have formed due to chromium substitution.

- **Fourier Transform Infrared Spectroscopy (FTIR)**

Fourier Transform Infrared Spectroscopy (FTIR) (PerkinElmer Spectrum 100) was employed to identify the functional groups and bonding structure within the bioglass. FTIR spectra were recorded in the range of 4000–400 cm^{-1} using the KBr pellet method. The presence of characteristic Si-O-Si, P-O, and Cr-O bonds was monitored to assess the impact of chromium substitution on the bioglass network.

- **Scanning Electron Microscopy (SEM)**

The surface morphology of the chromium-substituted bioglass was examined using Scanning Electron Microscopy (SEM) (JEOL JSM-6490LV). The samples were coated with a thin layer of gold to enhance conductivity before imaging. Energy-dispersive X-ray spectroscopy (EDS) was performed in conjunction with SEM to confirm the homogeneous distribution of chromium within the bioglass matrix.

- **Mechanical Testing**

The hardness of the bioglass samples was measured using a Vickers microhardness tester (Shimadzu HMV-2T). Compressive strength tests were conducted using a universal testing machine (Instron 3369) at a crosshead speed of 1 mm/min. The mechanical properties were assessed for bioglass samples with varying chromium concentrations to determine the optimal doping level.

- **In Vitro Bioactivity Testing**

The bioactivity of the chromium-substituted bioglass was evaluated by immersing the samples in simulated body fluid (SBF) at 37°C for up to 14 days. The formation of hydroxyapatite on the bioglass surface was analyzed using XRD, FTIR, and SEM, as indicators of bioactivity. The SBF solution was refreshed every 48 hours to maintain ion concentration and pH stability.

Statistical Analysis

All experiments were conducted in triplicate, and the results are presented as mean ± standard deviation. Statistical analysis was performed using one-way analysis of variance (ANOVA) followed by Tukey's post hoc test to evaluate the significance of differences between groups. A p-value of less than 0.05 was considered statistically significant.

Results

The synthesis and characterization of chromium-substituted 1393 bioglass were carried out to assess the impact of chromium incorporation on the material's structural, mechanical, and biological properties. The results are presented in the following sections.

- **Synthesis Outcomes**

Chromium was successfully incorporated into the 1393 bioglass matrix using the sol-gel method. The resulting bioglass exhibited a homogeneous composition with chromium concentrations varying from 0.5 to 5 mol%. The glass appeared to maintain a consistent and transparent structure without visible phase separation, indicating that chromium was effectively integrated into the glass network.

Structural Analysis

- **X-ray Diffraction (XRD)**

The XRD patterns of chromium-substituted 1393 bioglass samples demonstrated an amorphous structure, similar to the pure 1393 bioglass, which is characteristic of bioactive glasses. However, subtle shifts in the diffraction peaks were observed with increasing chromium content, suggesting minor changes in the glass network's structure. These shifts could be attributed to the incorporation of chromium ions into the silica network, potentially altering the network's connectivity and density.

- **Fourier Transform Infrared Spectroscopy (FTIR)**

FTIR analysis revealed that the incorporation of chromium led to slight modifications in the bioglass's vibrational modes. The characteristic Si-O-Si stretching bands showed minor shifts, indicating changes in the network structure due to chromium substitution. The intensity of the phosphate (P-O) vibrational bands also increased slightly, which might suggest a stabilization of phosphate groups in the presence of chromium.

Surface Morphology

- **Scanning Electron Microscopy (SEM)**

SEM images of the chromium-substituted bioglass samples revealed a smooth and uniform surface morphology across all chromium concentrations. At higher chromium content, the surface appeared slightly more dense and less porous compared to the pure 1393 bioglass, which could be indicative of an increased network connectivity and reduced glass porosity due to chromium incorporation. The homogeneous distribution of chromium within the bioglass matrix was confirmed by energy-dispersive X-ray spectroscopy (EDS) mapping.

Mechanical Properties

- **Hardness and Compressive Strength**

The mechanical testing results showed a significant improvement in the hardness and compressive strength of the chromium-substituted bioglass compared to the pure 1393 bioglass. Specifically, the hardness increased by approximately 15% at 2 mol% chromium concentration, while the compressive strength showed an improvement of about 20% at the same concentration. This enhancement in mechanical properties can be attributed to the densification of the glass network caused by chromium ion substitution, which likely increases the rigidity and resistance to deformation.

In Vitro Bioactivity

- **Simulated Body Fluid (SBF) Testing**

The bioactivity of the chromium-substituted bioglass was assessed by immersing the samples in simulated body fluid (SBF) and observing the formation of hydroxyapatite on the surface. XRD and FTIR analyses of the samples after immersion confirmed the formation of a hydroxyapatite layer, indicating that the bioglass retained its bioactivity despite chromium substitution. Notably, the rate of hydroxyapatite formation was slightly reduced at higher chromium concentrations (above 3 mol%), suggesting a potential trade-off between mechanical enhancement and bioactivity at higher levels of chromium doping.

Discussion

The results of this study demonstrate that chromium substitution in 1393 bioglass can significantly influence its structural, mechanical, and biological properties, making it a promising approach to developing advanced biomaterials for biomedical applications. The implications of these findings are discussed below.

- **Structural Modifications**

The X-ray diffraction (XRD) and Fourier Transform Infrared Spectroscopy (FTIR) analyses revealed that chromium incorporation led to subtle changes in the glass network. The shifts observed in the XRD patterns and FTIR spectra suggest that chromium ions are likely substituting for silicon or modifying the silica network in a way that increases the connectivity and density of the glass structure. This is consistent with previous studies on other ion-substituted bioglasses, where the incorporation of metal ions typically leads to changes in the glass network's structure, enhancing its rigidity and stability.

These structural modifications are crucial because they directly influence the material's mechanical properties. The densification of the glass network, as indicated by the SEM analysis, is likely responsible for the observed improvements in hardness and compressive strength. This suggests that chromium substitution can effectively enhance the mechanical robustness of 1393 bioglass, making it more suitable for load-bearing applications in bone repair and regeneration.

Enhanced Mechanical Properties

One of the most significant findings of this study is the enhancement of the mechanical properties of 1393 bioglass due to chromium substitution. The observed increases in hardness and compressive strength, particularly at chromium concentrations around 2 mol%, are promising. These improvements can be attributed to the role of chromium in increasing the cross-linking within the glass network, which in turn reduces the material's susceptibility to deformation and fracture.

This enhancement in mechanical strength is critical for expanding the application of bioglass to areas where mechanical stability is essential, such as in the repair of large bone defects or as coatings for metallic implants. The ability to tailor the mechanical properties of bioglass through chromium substitution opens up new possibilities for customizing materials to meet specific clinical needs.

Bioactivity and Chromium Concentration Trade-offs

The in vitro bioactivity tests demonstrated that chromium-substituted bioglass retains its ability to form hydroxyapatite in simulated body fluid (SBF), a key indicator of its potential to bond with bone tissue in vivo. However, the rate of hydroxyapatite formation was observed to decrease slightly at higher chromium concentrations, particularly above 3 mol%. This suggests that while chromium enhances mechanical properties, it may also slightly inhibit the bioactivity of the bioglass at higher doping levels.

This trade-off between mechanical enhancement and bioactivity is an important consideration for the application of chromium-substituted 1393 bioglass in biomedical contexts. For applications where mechanical strength is critical, a moderate level of chromium substitution (around 2 mol%) appears optimal, providing a balance between enhanced mechanical properties and acceptable bioactivity. For applications where bioactivity is paramount, lower concentrations of chromium or alternative doping strategies might be more suitable.

Potential Biomedical Applications

The findings of this study have significant implications for the development of advanced biomaterials. Chromium-substituted 1393 bioglass, with its enhanced mechanical properties and retained bioactivity, could be particularly beneficial in orthopedic applications where both strength and biointegration are required. This includes the potential use in bone grafts, coatings for orthopedic implants, and scaffolds for tissue engineering.

Additionally, the potential antimicrobial properties of chromium, though not specifically tested in this study, could provide added benefits in preventing post-surgical infections, further enhancing the clinical relevance of chromium-doped bioglass.

Future Directions

While this study provides valuable insights into the effects of chromium substitution on 1393 bioglass, further research is needed to optimize the concentration of chromium for specific applications. Additionally, in vivo studies are necessary to fully understand the biological interactions of chromium-substituted bioglass and to confirm its long-term biocompatibility and performance. Exploring the antimicrobial properties of chromium-doped bioglass could also offer new avenues for enhancing the functionality of this material in clinical settings.

Conclusion

This study has successfully demonstrated that chromium substitution in 1393 bioglass leads to significant improvements in its mechanical properties while maintaining its essential bioactivity. The incorporation of chromium into the bioglass matrix results in a denser and more connected glass network, which enhances hardness and compressive strength, making the material more suitable for applications where mechanical stability is critical.

However, the findings also indicate a trade-off between mechanical enhancement and bioactivity, particularly at higher chromium concentrations. While the bioactivity remains robust at moderate chromium levels, excessive doping could potentially reduce the material's ability to form hydroxyapatite, which is crucial for bone bonding. Therefore, an optimal chromium concentration must be identified to balance these properties effectively for specific biomedical applications.

The potential of chromium-substituted 1393 bioglass as a biomaterial for bone regeneration, implant coatings, and other medical applications is promising. The enhanced mechanical properties could enable its use in more demanding clinical scenarios, while its retained bioactivity ensures it can effectively bond with bone tissue. Moreover, the possibility of added antimicrobial benefits from chromium opens new avenues for further research.

Future work should focus on fine-tuning the chromium content for different applications, conducting in vivo studies to validate biocompatibility, and exploring the full range of biological effects that chromium substitution might offer. Overall, this research contributes to the growing body of knowledge aimed at developing advanced biomaterials that meet the evolving needs of regenerative medicine and orthopedics.

References

1. Hench LL. The story of Bioglass®. J Mater Sci Mater Med. 2006;17(11):967-78.
2. Hoppe A, Güldal NS, Boccaccini AR. A review of the biological response to ionic dissolution products from bioactive glasses and glass-ceramics. Biomaterials. 2011;32(11):2757-74.
3. Jones JR. Review of bioactive glass: From Hench to hybrids. Acta Biomater. 2013;9(1):4457-86.
4. Lakhkar NJ, Lee IH, Kim HW, Salih V, Wall IB, Knowles JC. Bone formation controlled by biologically relevant inorganic ions: role and controlled delivery from phosphate-based glasses. Adv Drug Deliv Rev. 2013;65(4):405-20.
5. Choudhary R, Kapoor S, Dubey AK, Kaur J, Basu B. Doping in bioglasses: A perspective review on the role of dopants in the biological and mechanical properties. J Mater Res Technol. 2019;8(5):5044-62.
6. Rahaman MN, Day DE, Bal BS, Fu Q, Jung SB, Bonewald LF, et al. Bioactive glass in tissue engineering. Acta Biomater. 2011;7(6):2355-73.
7. Salinas AJ, Vallet-Regí M. Bioactive ceramics: from bone grafts to tissue engineering. RSC Adv. 2013;3(31):11116-31.
8. Kaur G, Kumar V, Baino F, Mauro JC, Pickering KL, Kipkorir Z. Mechanical properties of bioactive glasses, ceramics, glass-ceramics and composites: State-of-the-art review and future perspectives. Mater Sci Eng C Mater Biol Appl. 2019;104:109895.
9. Wu C, Chang J. A review of bioactive silicate ceramics. Biomed Mater. 2013;8(3):032001.
10. Bellucci D, Cannillo V, Sola A. An overview of the effects of thermal treatments on bioactive glasses. Acta Biomater. 2015;13:1-15.
11. O'Donnell MD, Watts SJ, Law RV, Hill RG. Effect of P2O5 content in two series of soda lime phosphosilicate glasses on structure and properties—part II: physical properties. J Non Cryst Solids. 2009;355(12-13):851-60.
12. Gupta R, Xie C, Shukla R, Weir MD, Hamlekhan A, Lin NJ, et al. Evaluation of antimicrobial and osteogenic activities of bioactive glasses. Adv Funct Mater. 2019;29(24):1809590.

13. Zheng K, Sui B, Ilyas K, Boccaccini AR. Porous bioactive glass microspheres produced by flame synthesis: applications in tissue engineering and drug delivery. Acta Biomater. 2021;120:1-16.

14. Lusvardi G, Malavasi G, Menabue L, Saladini M. Synthesis, characterization and in vitro bioactivity of zinc-doped Na2O·CaO·2SiO2 glass. J Non Cryst Solids. 2009;355(7):388-93.

15. Li H, Chang J. Preparation, characterization, and in vitro release of gentamicin from PHBV/bioglass composite microspheres. J Mater Sci Mater Med. 2005;16(2):143-8.

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20 IoT-based Cloud Integrated Smart Classroom for Intelligent and Sustainable Campus

Dr. Ranjan Kumar Mondal*
Assistant Professor, Department of CSE, Swami Vivekananda University, Kolkata, WB, India

***Corresponding Author:** ranjankm@svu.ac.in

Abstract

With the advent of intelligent classroom technologies, students now expect more from their university campuses and are open to trying out new teaching strategies. IoT and cloud computing technologies can offer solutions for an innovative and sustainable campus to enhance student's learning strategies and increase the effectiveness of regular institution operations. This study focuses on integrating cloud computing into the educational system and the Internet of Things paradigm in teaching. IoT in education gives students access to cutting-edge tools that support their ability to think creatively and logically about societal issues. Intelligent systems, unified campus portal services, security, and maintenance systems are all provided by IoT-based cloud computing technologies. The digitally connected campuses improve both environmental sustainability and student learning. Using cell phones and PDAs, students can access their homework assignments and exam results through internet portals. You may post videos online and on the cloud. Students can participate in remote classroom lectures thanks to lecturing. IoT devices track absentee students, provide warnings to encourage regular focus on academic work, and locate misplaced personal belongings. Payments at the office, cafeteria, and other administrative tasks may be accomplished easily using digital devices. The microcontroller board, sensor module, and wireless and wired connections comprise the Internet of Things hardware. The software module processes and transmits data to and from sensor modules to cloud storage. This paper describes how IOT and Cloud Infrastructure restructure traditional education and learning methods.

Introduction

Universities are now paying more attention to cloud computing and the Internet of Things to create intelligent campuses [1]. An intelligent campus comprises several interconnected peripherals, infrastructure, and facilities that offer bright lighting, security, tracking, and the effective use of resources like water, energy, and labor [2, 3]. Teaching and overseeing the classroom's operations must take up equal time under the traditional classroom paradigm. Mentoring and keeping an eye on the student's academic-related activities is tiresome. It is difficult for the faculty and the administration of the school to keep a careful eye on students' academic progress. Therefore, a new system that manages workflow and drastically reduces faculty time spent on administrative tasks is required to ensure that class hours are used to their fullest potential [4]. This allows faculty to spend more time teaching and interacting with students rather than managing their workload. This study presents a technique that reduces human secondary labor by utilizing IoT, cloud computing, and application development platforms. With this deployment, faculty members could concentrate more on their core teaching responsibility and less on overseeing the classroom's workflow.

IoT and Cloud-based Smart Classroom

A literature review [5-8] shows the various IoT and Cloud-based Smart Classroom Systems. One such modified ARM microcontroller is used in the Internet of Things-based Smart Classroom Environment system. This approach is employed in faculty administration, resource management, and attendance tracking. The learner's or guest's whereabouts were monitored using ID cards and wristbands. This innovative classroom system also handles dynamic ticketing, intelligent parking, etc. [5].

An additional system uses an RFID security system to grant access to an intelligent bench in a smart classroom via a touch-based interface and a cloud-based framework storage system. These interfaces, which allow students to interact with notepads while listening to the lecture, are available at each desk in the classroom. They provide simple comprehension and resource virtualization for the students. The school system changed due to this new technical development [6].

To Maximize Classroom Utilization, An IoT and AI technology implementation guide was created for an innovative campus. The system has sensors that measure the number of students in each lecture hall on campus. The system's characteristics include tracking live occupancy, gathering attendance data for 250 courses across two sessions, identifying conducted, postponing lecture hours, and administering examinations. Artificial intelligence techniques are also employed to forecast attendance. The system uses a mechanism that optimally predicts student attendance to allocate classrooms [7].

The Smart Campus Teaching Platform, based on the 5G network deployment architecture, establishes an online teaching platform. A localization method is used to get the student's position information and track his presence in the classroom. 5G network technology was used in the smart classroom's implementation to increase data transmission and student check-in time computation speed [8].

RFID, IoT, AI, and cloud storage systems are a few of the technologies that may be used to construct an intelligent classroom. Data transfer from sensors to clouds may experience extra delays and security issues. The system should provide intelligent, sustainable cloud computing [9–11].

This study explains how IoT and cloud infrastructure effectively reorganize conventional approaches to teaching and learning by leveraging cloud storage to manage intelligent applications that facilitate communication between students and teachers and between different objects and IoT sensors.

- **Proposed System**

The suggested Internet of Things (IoT)-based cloud computing technology offers innovative campus, security, and maintenance systems to support scientific research, teaching, staff, and student management, online billing, attendance monitoring, homework or assignment monitoring, and the recovery of misplaced books, laptops, or other necessary items. Smartphones and PDAs are valuable tools for educators and students to utilize in the classroom. Payments at the cafeteria, office, and other administrative tasks may be made conveniently using the innovative campus system. Videos offline and online: If students miss class, they can still participate in the lectures virtually, thanks to lecturing. The system's hardware platform comprises numerous sensor modules with wired and wireless connectivity—a software module processes sensor data and stores it in the cloud. Cloud networks are built on intelligent networking equipment, such as switches, routers, gateways, and WiFi routers. Figure 1 illustrates the suggested system techniques that improve administrative tasks, teaching, and learning.

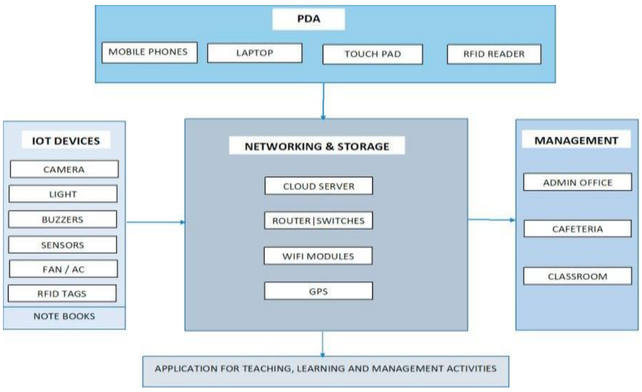

Fig. 1: IoT-based Cloud Integrated Smart Classroom

Any computationally smart device linked to the Internet of Things through remote access may build an intelligent, effective, and efficient virtual classroom environment for delivering education at any time or place. Figure 2 displays the suggested Smart Classroom application.

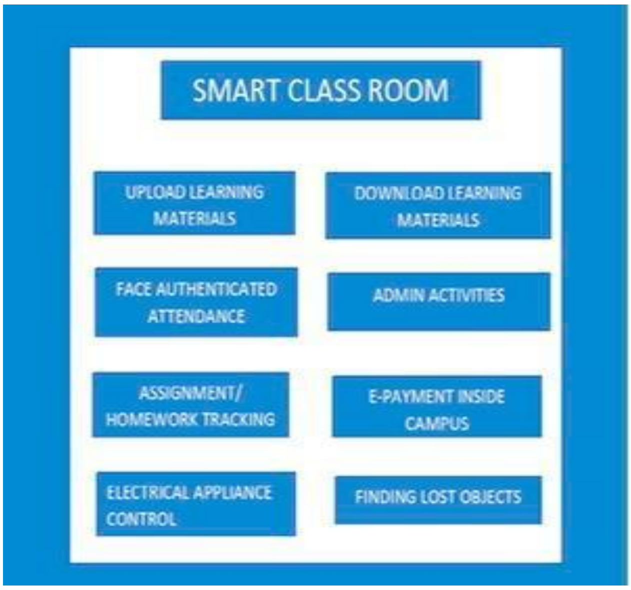

Fig. 2: Proposed Application for Smart Classroom

RFID-tagged lost personal items can be located using location tracker systems. Non-erasable RFID tags are connected to laptops, notebooks, and other items; lost items can be located using the Internet of Things to track their whereabouts. The IoT-enabled visitor ID card is provided to the campus visitor. He should use a GPS module to locate the workplace and cafeteria. An RFID reader based on the Internet of Things and a buzzer alarm system managed by a microcontroller are two examples of the infrastructure in an intelligent campus setting. This subsystem will monitor the pupils and carry out the assigned tasks. Data is detected and gathered from various sources, including cameras, GPS, and RFID tags. Direct interactions between multiple sources, as well as between routers, gateways, etc., are made possible by IoT technology.

Facial recognition is used in the open-source program. Cv to update student attendance automatically. When a student walks into class, the camera automatically records their presence and absence by capturing their face, extracting objects, creating 3D points from the video, and comparing it to a database to discover a comparable image from a cloud server. The student attendance tracking tool allows teachers to monitor daily, monthly, and total attendance. The teachers may include an explanation for their absence. The parent or legal guardian is also notified when a pupil is absent. Figure 3a depicts the Face authenticated Attendance system.

This system makes it simple to organize assignments, homework, and attendance. Teachers will be allowed to publish assignments along with their due dates. Email addresses associated with the student will get notifications—students in the cloud post assignment answers. A list of students' names and ID numbers who turn in their work on time will be automatically tracked and distributed to the teachers.

IoT enables automatic control of lights, fans, and cameras in classrooms. A sensor that detects student movement regulates electrical equipment such as lights, fans, and air conditioners. Upon pupils' arrival, the classroom lights and fans will be automatically turned on. If they exit the classroom, the sensor will alert the microcontroller and wait awhile. The microcontroller will turn off the lights, fan, and air conditioning if no human activity is detected and the classroom is vacant. Thus, the suggested smart classroom uses less electricity. Fig. 3b illustrates how electrical appliances are controlled.

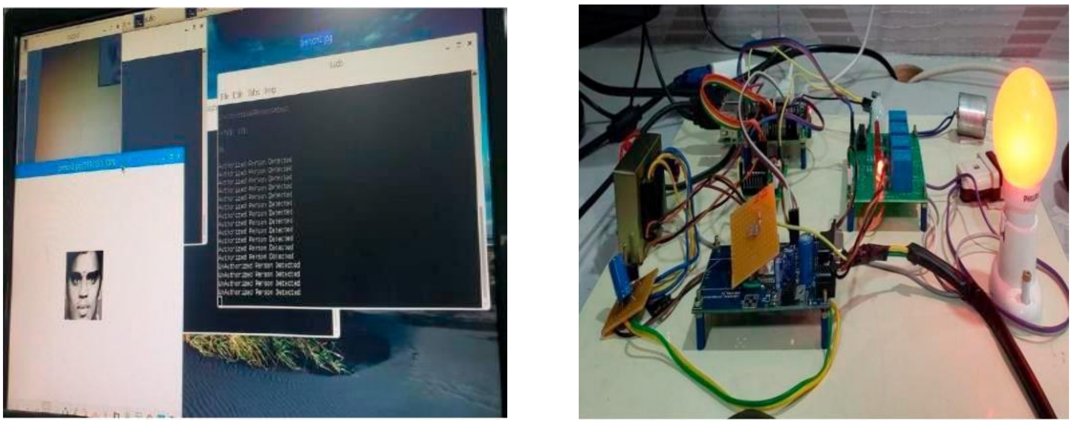

Fig. 3: (a) Face aauthenticated Attendance system.(b) Electrical Appliances Controlling

IoT controls classroom activities, and students who do the assigned task can use the system within the allocated time. RFIDs, or radio frequency identification, are enabled on student ID cards. The system will keep an RFID for every username that has been registered. Every classroom will have an RDIF reader installed in front of it and a buzzer system run by a microcontroller. The students on the RFID list who turned in their assignments by the deadline will have their information transferred to the RFID reader. Only those who finished their assignments by the deadline can enter the classroom. The buzzer will notify the student to meet with the faculty mentor if they attempt to enter the classroom without turning in their work.

Conclusion

The IoT-based Cloud Integrated Smart Classroom will evolve the educational environment and lead to high efficiency and effectiveness of classroom teaching methods for an innovative and sustainable campus. This approach will foster sincerity in completing assignments on time among the student body. Rather than overseeing and controlling the classroom's workflow, faculty and administration should devote more time to teaching and learning. Thus, the suggested educational system model provides an intelligent, cost-effective, and ecologically sustainable campus.

References

1. Srinivas, Voore Subbarao and Pavithr.(2019) “A Survey On Internet Of Things Based Smart, Digital Green And Intelligent Campus.” IEEE 2019 4th International Conference on Internet of Things: Smart Innovation and Usages: 1-6
2. Karan Phougat, Sachin Wakurdekar, Samarth Pruthi and Mohit Sinha.(2017) “An IOT approach for developing Smart Campus.”International Journal of Innovative Research in computer and communication Engineering, 5(4):7405-7412
3. Pagliaro F, Mattoni B, Gugliermenti F, Bisegna F, Azzaro B, Tomei F and Catucci S. (2016). “A roadmap toward the development of Sapienza Smart Campus.” In Proceedings of the International Conference on Environment and Electrical Engineering, Italy: 1–6.
4. Nie, X(2013). “Constructing Smart Campus Based on the Cloud Computing Platform and the Internet of Things.” In Proceedings of the 2nd International Conference on Computer Science and Electronics Engineering (ICCSEE 2013), Hangzhou, China: 1576–1578
5. Asim Majeed and Mahmood Ali. (2018) “How Internet-of-Things (IoT) Making the University Campuses Smart?.” IEEE 8th Annual Computing and Communication Workshop and Conference (CCWC): DOI: 10.1109/CCWC.2018.8301774
6. Sumeet Bajaj, Shreyas Kumbhakarn and Apeksha Bandekar.(2018) “Smartbenches In Classroom.” International Conference On Inventive Research in Computing Applications (ICIRCA 2018).
7. Thanchanok Sutjarittham, Hassan Habibi Gharakheili, Salil S. Kanhere and Vijay Sivaraman.(2019) “Experiences with IoT and AI in a Smart Campus for Optimizing Classroom Usage” of IEEE Internet Of Things Journal 1:1-13
8. Xin Xu, Dan Li, Mengyao Sun, Shichao Yan, Shujiang Yu, Gunasekaran Manogaran and George mastorakis. (2019) “Research on Key Technologies of Smart Campus Teaching Platform Based on 5G Network” Special Section on Roadmap To 5G: Rising To The Challenge, 7: 20664 - 20675
9. Liu, M and Li L. (2018). “The construction of smart campus in universities and the practical innovation of student work.” Proceedings of the International

Conference on Information Management & Management Science, Chengdu, China:154–157.

10. Zhicheng D and Feng L. (2019). “Evaluation of the Smart Campus Information Portal” in Proceedings of the 2nd International Conference on Education and E-Learning, Bali, Indonesia: 73–79.

11. Pompei L, Mattoni B, Bisegna F, Nardecchia F, Fichera A, Gagliano A and Pagano, A (2018). “Composite Indicators for Smart Campus: Data Analysis Method” Proceedings of the IEEE International Conference on Environment and Electrical Engineering: 1–6.

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Review Paper on 3D Printing: Advancements, Applications, and Challenges

Joydip Roy*
Department of Mechanical Engineering, Swami Vivekananda University, Kolkata, India

***Corresponding Author:** joydiptutanroy@gmail.com

Abstract

3D printing, also known as additive manufacturing, has revolutionized the manufacturing industry by enabling the creation of complex structures with unprecedented precision. This review paper provides an in-depth analysis of the advancements in 3D printing technology, its wide range of applications across industries, and the challenges it faces. The paper highlights key developments in materials, printing techniques, and software that have expanded the capabilities of 3D printing. Additionally, it explores the growing role of 3D printing in healthcare, aerospace, automotive, and consumer products, while discussing environmental concerns, intellectual property issues, and the need for standardization in the industry. Finally, the paper identifies future trends and opportunities for further innovation in 3D printing.

Introduction

3D printing has emerged as one of the most transformative technologies of the 21st century, offering new possibilities in manufacturing, prototyping, and design across various sectors. Unlike traditional subtractive manufacturing methods, 3D printing builds objects layer by layer using materials such as polymers, metals, ceramics, and composites. Originally developed in the 1980s, the technology has evolved significantly, with applications ranging from rapid prototyping to the production of fully functional components. The widespread adoption of 3D printing is driven by its ability to create highly customized, complex geometries while minimizing waste and reducing lead times. As industries seek more efficient and sustainable manufacturing methods, 3D printing continues to push the boundaries of innovation. However, despite its benefits, the technology still faces challenges in terms of scalability, material limitations, and regulatory compliance, which must be addressed to fully realize its potential.

Literature Review

The evolution of 3D printing has been well-documented in scholarly literature, with numerous studies focusing on the development of new materials, processes, and applications. Early research on additive manufacturing, pioneered by Charles Hull in 1986, laid the foundation for the modern 3D printing techniques used today. A significant body of research has explored the various printing methods, such as stereolithography (SLA), fused deposition modeling (FDM), selective laser sintering (SLS), and direct metal laser sintering (DMLS). Each technique has its advantages and limitations, with material properties, speed, and resolution playing a critical role in their adoption for specific applications. Recent studies have focused on the integration of smart materials and multi-material printing, expanding the functional capabilities of printed objects.

In terms of applications, the literature highlights the significant impact of 3D printing in the healthcare sector, particularly in the production of customized implants, prosthetics, and even bioprinting of tissues and organs. The aerospace and automotive industries have embraced the technology for lightweight, high-strength components that reduce fuel consumption and manufacturing costs. Despite these advancements, the literature also addresses the challenges associated with 3D printing, such as material inconsistency, limited post-processing options, and concerns over the intellectual property rights of digital designs. Researchers have emphasized the need for developing standardized testing protocols and regulatory frameworks to ensure the safety and reliability of 3D-printed products.

Methodology

This review paper is based on an extensive literature survey of scholarly articles, patents, industry reports, and case studies related to 3D printing. The key focus areas include the advancements in printing technologies, the development of new materials, and the various applications of 3D printing across industries. For this review, sources from 2010 to 2023 were analyzed to capture the latest trends and challenges in the field. A systematic approach was used to categorize the research findings into sections covering technological advancements, industrial applications, and potential challenges. The study also includes an analysis of the environmental and economic implications of 3D printing, particularly in the context of sustainable manufacturing practices.

Advancements in 3D Printing Technology

- **Materials**

One of the most significant advancements in 3D printing is the development of new materials. Initially, 3D printing was limited to a few plastics, but recent innovations have expanded the range to include metals, ceramics, composites, and even bio-materials. High-performance polymers, such as PEEK and ULTEM, are now used for demanding aerospace and medical applications. Additionally, the advent of metal 3D printing has opened new possibilities for producing parts with intricate geometries that would be impossible using traditional methods.

- **Printing Techniques**

Over the years, several new printing techniques have been developed, each with its specific advantages. Stereolithography (SLA) offers high resolution and is commonly used in dental and jewelry applications. Fused Deposition Modeling (FDM) remains one of the most accessible and widely used methods due to its low cost and ease of use. Selective Laser Sintering (SLS) and Direct Metal Laser Sintering (DMLS) are gaining popularity for their ability to produce durable, functional metal parts. Furthermore, multi-material printing and hybrid manufacturing techniques are on the rise, enabling the integration of different materials in a single print job, which adds functionality to the final product.

- **Software and Design Tools**

The advancement of design software has played a crucial role in the growth of 3D printing. Computer-Aided Design (CAD) and simulation software allow for the creation of complex geometries, optimized structures, and the testing of mechanical properties before production. The integration of AI and machine learning in these software tools has further enhanced the precision and efficiency of 3D printing, making it easier to design and manufacture products with high accuracy.

Applications of 3D Printing

- **Healthcare**

3D printing has had a profound impact on healthcare by providing custom prosthetics, dental implants, and even the possibility of bioprinting tissues and organs. Patient-specific models based on CT or MRI scans are used for surgical planning, reducing risks and improving outcomes. Bioprinting, though still in its infancy, holds the potential for creating viable tissues and organs in the future.

- **Aerospace**

The aerospace industry has adopted 3D printing for producing lightweight and durable components, such as engine parts and airframes. The ability to produce complex geometries with minimal material waste has led to significant weight reductions in aircraft, which improves fuel efficiency.

- **Automotive**

In the automotive sector, 3D printing is used for rapid prototyping, tooling, and even the production of end-use parts. It allows manufacturers to reduce lead times, cut costs, and create more fuel-efficient vehicles by producing lightweight components.

- **Consumer Products**

In consumer goods, 3D printing enables mass customization of products such as footwear, eyewear, and jewelry. Brands like Adidas and Nike have already incorporated 3D printing into their design processes to create highly personalized products tailored to individual customer needs.

Challenges in 3D Printing

Despite its potential, 3D printing faces several challenges that need to be addressed for its widespread adoption. These challenges include:

- **Material Limitations:** While there has been progress in the development of new materials, the range of compatible materials remains limited compared to traditional manufacturing methods.
- **Scalability:** 3D printing is still slower than traditional manufacturing techniques, making it difficult to scale up for mass production.
- **Post-Processing:** Many 3D-printed parts require extensive post-processing, such as sanding, painting, or curing, which adds time and cost to the production process.
- **Environmental Impact:** Although 3D printing reduces material waste, the environmental impact of energy-intensive printing processes and the use of non-recyclable materials is a concern.

Future Trends

As 3D printing technology continues to evolve, several trends are expected to shape its future:

- **Sustainability:** There is increasing interest in developing eco-friendly materials and energy-efficient printing techniques.
- **Bio Printing:** The bio printing of tissues and organs holds promise for the future of healthcare, though significant research is still needed.
- **Industry 4.0 Integration:** The integration of 3D printing into smart factories and the Internet of Things (IoT) will enable real-time monitoring and optimization of manufacturing processes.

Conclusion

3D printing has come a long way since its inception, transforming industries with its ability to create complex, customized products with minimal waste. While it offers numerous advantages, challenges such as material limitations, scalability, and environmental impact remain. Continued research and innovation are needed to address these issues and unlock the full potential of 3D printing. With advancements in materials, software, and printing techniques, the future of 3D printing looks promising, offering new opportunities for sustainable manufacturing and unprecedented design freedom.

References

1. Hull, C. W. (1986). Apparatus for production of three-dimensional objects by stereolithography. US Patent No. 4575330.
2. Gibson, I., Rosen, D. W., & Stucker, B. (2014). Additive manufacturing technologies: 3D printing, rapid prototyping, and direct digital manufacturing. Springer.
3. Ngo, T. D., Kashani, A., Imbalzano, G., Nguyen, K. T. Q., & Hui, D. (2018). Additive manufacturing (3D printing): A review of materials, methods, applications, and challenges. Composites Part B: Engineering, 143, 172-196.
4. Murphy, S. V., & Atala, A. (2014). 3D bioprinting of tissues and organs.Nature biotechnology, 32(8), 773-785.
5. Attaran, M. (2017). The rise of 3-D printing: The advantages of additive manufacturing over traditional manufacturing. Business Horizons, 60(5), 677-688.
6. Weller, C., Kleer, R., & Piller, F. T. (2015). Economic implications of 3D printing: Market structure modeling and business model innovation. Technological Forecasting and Social Change, 102, 225-239.
7. Huang, Y., Wu, X., & Zhang, L. (2019). A review of 3D printing technologies for food applications. Critical Reviews in Food Science and Nutrition, 59(3), 1-15.
8. ASTM International. (2018). Standard Guide for Additive Manufacturing Technologies.ASTM F3091-14.
9. Berman, B. (2012). 3-D printing: The new industrial revolution. Business Horizons, 55(2), 155-162.
10. Kumar, A., & Singh, M. (2020). A review on the applications of 3D printing technology in manufacturing. Materials Today: Proceedings, 22, 1632-1637.

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Localized Solar Energy Prediction with Machine learning

Rituparna Mitra*

Department of Electrical Engineering, Swami Vivekananda University, Barrackpore, Kolkata, India

***Corresponding Author:** rituparnam@svu.ac.in

Abstract

The process of producing solar energy is sporadic and dependent on the environment. This may result in the creation of erratic and fluctuating electricity, harming the power grid and resulting in financial losses. Predicting solar energy generation is crucial for improved control over electricity production. In this context, big data and machine learning algorithms have produced outstanding outcomes. In this investigation, the effectiveness of two distinct Regression and classification are two machine learning techniques for predicting solar energy production. While the classification strategy predicts whether the power output will be above or below a given threshold, the regression approach predicts the actual power output. With mean absolute errors and root mean square errors of 0.046 and 0.11, respectively, the random forest regressor technique was shown to have the best accuracy. It did not, however, effectively forecast peak power values, which could have resulted in larger mistakes. Peak power values were more accurately classified using the long short-term memory method. According to the study's findings, classification models might be more generalizable than regression models. The suggested method is useful for analyzing model performance and raising prediction accuracy.

Introduction

Solar power generation has emerged as a key component in the shift to cleaner and more environmentally friendly electricity production in the context of the growing global demand for sustainable energy sources. Effective integration of solar energy into the electricity grid is significantly hampered by its intermittent and weather-dependent character. In order to overcome this difficulty, accurate solar power generation forecasting is essential for improving energy trade, grid management, and resource efficiency. Machine learning (ML) techniques have advanced over time and transformed several fields, including energy forecasting. These methods could lead to more precise and trustworthy projections of solar power generation, which would help grid operators, politicians, and energy producers make decisions.

The application of many machine learning (ML) methods, including artificial neural networks (ANN), random forests (RF), decision trees (DT), extreme gradient boosting (XGB), and long short-term memory (LSTM), in PV solar power output forecasting is highlighted.applicability in multiple fields. Recent solar forecasting research is compiled in Table 1 (reported from Rahimi et al., 2023)). The best to worst algorithms for forecasting PV solar power output were compared in a similar study, and the results showed that the ANN model produced the best MAE, RMSE, and R2 with scores of 0.4693, 0.8816, and 0.9988, respectively. The other algorithms for the same purpose were RF, DT, XGB, and LSTM. According to the study, the XGB method outperforms the established algorithms (ANN, RF) in PV solar power production forecasting; however, it necessitates the use of additional sophisticated techniques (Essam et al., 2022).

An extremely recent investigation carried out in Lubbock, Texas, made use of a dataset that included detailed 5-min observations of temperature, humidity, wind direction, wind speed, and solar radiation from 2012 to 2022. The study demonstrated the superiority of LSTM and RF models over DT, GB, CNN, and ANN. Remarkably, the models with RF and LSTM yielded the lowest mean squared error (MSE) rates, at 2.06% and 2.23%, respectively, and the greatest R2 values, at 0.977 and 0.975, according to Balal et al. (2023).

Particularly focusing on LSTM models, two studies highlighted their forecasting ability and robustness. In order to get good results in forecasting PV power generation, these studies investigated LSTM architectures and hyperparameter tweaking (Harrou et al., 2020; Liu et al., 2021).

In a different study, the UNISOLAR Solar Generation Dataset—which includes two years' worth of data gathered at La Trobe University in Victoria, Australia—was used to predict solar energy generation. This dataset included important meteorological information such relative humidity, wind direction, speed, and apparent temperature as well as air and dew point temperatures. Using a zero-infated model to highlight the effectiveness of the RF, XGB, and ConvLSTM2D algorithms, the study cleverly handled the problem of zero-skewness in solar energy generation data and produced low (RMSE) values (Gandhi et al., 2023). Moreover, research efforts were expanded to Eastern India, where meteorological parameters' effects on solar PV power output were evaluated through the use of embedded machine learning models, including voting, stacking, bagging, and boosting.These models were verified using field data from a solar PV power plant with a capacity of 10 kWp, offering important information for greenfield solar projects in eastern India. The algorithms for voting and stacking performed better, with 313.07 RMSE, 0.96 R2 -score for voting and 314.9 RMSE, 0.96 R2 -score for stacking (Chakraborty et al., 2023). Finally, hybrid models that combined the features of Gaussian Process Regression (GPR) and Long Short-Term Memory (LSTM) demonstrated promise in forecasting consistent power generation. The enhanced accuracy of these hybrid models provides a dependable method for future solar power forecasting applications (Lim et al., 2022; Wang et al., 2021). The effectiveness of the SVR, ANN, DT, RF, Generalized Additive Models (GAM), and XGB algorithms on a 24 kW solar installation. The ANN was shown to be the most accurate model for predicting energy production among these (Ledmaoui et al., 2023). ANN, LSTM, and XGB were integrated into a novel deep learning algorithm named DSE-XGB, which outperformed the separate deep learning algorithms. This strategy produced a significant increase in R2 value of 10%–12% compared to other models, demonstrating increased consistency and stability across multiple case studies, even under shifting weather circumstances (Khan et al., 2022).Another study used machine learning methods, such as Gaussian Process Regression (GPR), to predict PV power by taking into account the temperature of the solar PV panels, ambient temperature, solar flux, time of day, and relative humidity. With RMSE, MAE, and R2 values of 7.967, 5.302, and 0.98, respectively, and great performance and accuracy, GPR was found to be the most dependable model (Zazoum, 2022). The field saw advancements in deep learning-based frameworks with the release of the physics-constrained LSTM (PC-LSTM) model. This model demonstrated better forecasting ability and robustness against sparse data, outperforming typical LSTM models. Compared to traditional machine learning and statistical methods, PC-LSTM demonstrated more accuracy (Luo et al., 2021).

The study produced strong proof of the feedforward neural networks and spatiotemporal (FFNNST) model's effectiveness, since it continuously outperformed individual models in the job of predicting sun radiation. Notably, it was discovered that, in order to successfully implement the FFNNST model in diverse geographical settings, careful consideration of the number of locations is just as important as optimizing neuron counts within the feedforward neural networks (FFNN) component (Rodríguez et al., 2021).

Table 1: Summary of recent studies for solar forecasting using machine learning, reported from Rahimi et al. (2023)

References	Time ahead	Input variables	Output variable	Forecasting	Method error	Comparison
Persson et al., (2017)	Daily	Temperature, air pressure, wind	PV power	Random forest	MAPE = 8.5%	RF > GBDT
Liu et al., (2015)	Daily	Temperature, relative humidity, cloud cover, precipitation	PV power	Boosting	RMSE = 9.48%	Boosting > AR
Flynn and Larsen (2022)	Daily	PV power	PV power	Timeseries	MSE = 16.24	TS > SARIMA
Yang (2019)	Hour	Irradiation	PV power	SVR	MAE = 37.04	SVR > NAM > SP
Hajirahimi and Khashei (2022)	Hour	Irradiation, temperature	PV power	Polynomial regression	MAPE = 10.51%	-
Hussain and AlAlili (2017)	Daily	Humidity, temperature, wind speed	PV power	WD-ANN	RMSE = 19.663% MAE = 10.349%	WD-ANN > ANN
Prasad et al., (2019)	6 h	Solar irradiance, temperature, PV output	PV power	WD-BCRF	RMSE = 32.12% MAE = 20.64%	WD-BCRF > WDSVM > RF
Gürtürk et al., (2022)	10 min	Irradiation	PV power	ANN	RMSE = 6%	ANN > ARIMA

Data Collection

The Desert Knowledge Australia Solar Centre (DKASC), a real solar technology demonstration facility, provided the data used in this study. Fig. 1 shows Alice Springs, a town in the Northern Territory recognized for its plentiful solar resources in an arid desert setting, situated within the Desert Knowledge Precinct. With its unique integration into the surrounding natural environment, DKASC is regarded as the largest multi-technology solar demonstration facility in the southern hemisphere (Centre, 2023).

Data from other installations were available in the database, and Table 2's summary of the First Solar installation's specifications piqued the study's curiosity.

Investigative Data Analysis

To obtain a thorough grasp of a dataset's properties, structure, and important trends, exploratory data analysis (EDA) is performed. It forms the basis for problem-solving decisions that are based on data. Table 3 lists the dataset's current features along with their designated units.Figure 2a shows that 61% of recorded values are less than 0.1 kW, which corresponds to times when solar panels were not in use. A thorough investigation was carried out to provide an explanation for the finding that panels were inactive for more than half of the time.

(a)

(b)

Fig. 1: a Satellite image of Alice spring location where PV solar modules are installed, b desert knowledge Australia solar center (DKASC)

Table 2: Cadmium telluride technology (CdTe) thin-flm modules

Array rating	6.96 kW
Panel rating	73 W
Number of panels	96
Panel type	First Solar FS-272
Array area	69.12 m^2
Type of tracker	N/A
Inverter size/type	6 Kw, Fronius Primo 6.0-1
Installation completed	Mon, 3 Nov 2008
Array tilt/azimuth	Tilt = 20, Azi = 0 (Solar North)

Table 3: Dataset Features and Units

Timestamp	Min
Active power	kW
Temperature	°C
Relative humidity	%
Wind speed	m/s
Win direction	°
Rainfall	mm
Global horizontal irradiation	W/m^2
Diffuse horizontal irradiation	W/m^2
Irradiation global tilted	W/m^2
Irradiation diffuse tilted	W/m^2

Algorithms that assume balanced classes may perform less well when dealing with imbalanced datasets. Because they effectively handle class imbalances, ensemble methods like random forest or boosting approaches like XGB can be especially effective in these kinds of situations. The histograms are accompanied by the Kernel Density Estimation (KDE) curves, which use data smoothing techniques to reduce noise and reveal underlying data trends. The KDE curves provide an approximation of the probability density function for the continuous random variable. Curve Fig. 2b's bimodal distribution is noteworthy because it shows two prominent peaks that correspond to regions of the distribution that have a high concentration of data points, designating them as focal points. These peaks are essential for making it easier to identify concentrated data points and possibly identify underlying patterns or unique data subgroups.

Conclusion

This study confirms many of the points made in a number of scholarly studies. Through the use of exploratory data analysis, it is now possible to better understand how certain meteorological factors, including wind speed, affect the efficiency and ability of photovoltaic panels to cool. Temperature peaks are strongly positively correlated and have a linear connection with global horizontal irradiance, rather than representing the optimal PV efficiency.

Rain showed to be a natural source of cleaning for PV panels against dust and pollution, but almost no link was seen with other variables like relative humidity and precipitation. The model decreased when temperature with weak correlation was excluded, but a normal distribution remained, indicating that variables were significant when the correlation was over 0.38 and even with less skewness. Furthermore, there was a substantial link between global tilted irradiation and global horizontal irradiation; however, the experiment results indicated that there was no effect on model performance, leading to its elimination to prevent redundancy.

References

1. Abiola-Ogedengbe, A., Hangan, H., & Siddiqui, K. (2015). Experimental investigation of wind efects on a standalone photovoltaic (PV) module. Renewable Energy, 78, 657–665. https://doi.org/10.1016/j.renene.2015.01.037
2. Ahmed, R., Sreeram, V., Mishra, Y., & Arif, M. D. (2020). A review and evaluation of the state-of-the-art in PV solar power forecasting: Techniques and optimization. In Renewable and sustainable energy reviews (Vol. 124). Elsevier. https://doi.org/10.1016/j.rser.2020.109792
3. Al-Ghezi, M. K. S., Ahmed, R. T., & Chaichan, M. T. (2022). The influence of temperature and irradiance on performance of the photovoltaic panel in the

middle of Iraq. International Journal of Renewable Energy Development, 11(2), 501–513. https://doi.org/10.14710/ijred.2022.43713

4. Balal, A., Jafarabadi, Y. P., Demir, A., Igene, M., Giesselmann, M., & Bayne, S. (2023). Forecasting solar power generation utilizing machine learning models in Lubbock. Emerging Science Journal, 7(4), 1052–1062. https://doi.org/10.28991/ESJ-2023-07-04-02
5. Bright, J. M., Babacan, O., Kleissl, J., Taylor, P. G., & Crook, R. (2017). A synthetic, spatially decorrelating solar irradiance generator and application to a LV grid model with high PV penetration. Solar Energy, 147, 83–98. https://doi.org/10.1016/j.solener.2017.03.018
6. Chakraborty, D., Mondal, J., Barua, H. B., & Bhattacharjee, A. (2023). Computational solar energy—Ensemble learning methods for prediction of solar power generation based on meteorological parameters in Eastern India. Renewable Energy Focus, 44, 277–294. https://doi.org/10.1016/j.ref.2023.01.006
7. Corbin, C. D., & Zhai, Z. J. (2010). Experimental and numerical investigation on thermal and electrical performance of a building integrated photovoltaic–thermal collector system. Energy and Buildings, 42(1), 76–82. https://doi.org/10.1016/j.enbuild.2009.07.013
8. Coskun, C., Toygar, U., Sarpdag, O., & Oktay, Z. (2017). Sensitivity analysis of implicit correlations for photovoltaic module temperature: A review. Journal of Cleaner Production, 164, 1474–1485. https://doi.org/10.1016/j.jclepro.2017.07.080
9. Desert Knowledge Australia Centre. (2023). 15/09/2023. Download data. Location (e.g. Alice Springs). https://dkasolarcentre.com.au/source/alice-springs/dka-m6-a-phase. Date accessed: 27/06/2023.
10. Essam, Y., Ahmed, A. N., Ramli, R., Chau, K. W., Idris Ibrahim, M. S., Sherif, M., Sefelnasr, A., & El-Shafe, A. (2022). Investigating photovoltaic solar power output forecasting using machine learning algorithms. Engineering Applications of Computational Fluid Mechanics, 16(1), 2002–2034. https://doi.org/10.1080/19942060.2022.2126528
11. Flynn, H. B., & Larsen, G. (2022). Investigating the application of Kalman filters for real-time accountancy in fusion fuel cycles. Fusion Engineering and Design, 176, 113037. https://doi.org/10.1016/j.fusengdes.2022.113037
12. Gandhi, K., Shah, A., Viswanath, V., Ranka, P., Dedhia, U., & Patil, N. (2023). Predicting solar energy generation with machine learning based on AQI and weather features. https://doi.org/10.21203/rs.3.rs-3178713/v1
13. Gürtürk, M., Ucar, F., & Erdem, M. (2022). A novel approach to investigate the effects of global warming and exchange rate on the solar power plants. Energy, 239(Part D), 122344. https://doi.org/10.1016/j.energy.2021.122344

14. Gwandu, B. A. L., & Creasey, D. J. (1995). Humidity: A factor in the appropriate positioning of a photovoltaic power station. Renewable Energy, 6(3), 313–316. https://doi.org/10.1016/0960-1481(95)00073-S
15. Hajirahimi, Z., & Khashei, M. (2022). Hybridization of hybrid structures for time series forecasting: A review. Artificial Intelligence Review. https://doi.org/10.1007/s10462-022-10199-0
16. Harrou, F., Kadri, F., & Sun, Y. (2020). Forecasting of photovoltaic solar power production using LSTM approach. In Advanced statistical modeling, forecasting, and fault detection in renewable energy systems. IntechOpen. https://doi.org/10.5772/intechopen.91248
17. Hasan, K., Yousuf, S. B., Tushar, M. S. H. K., Das, B. K., Das, P., & Islam, M. S. (2022). Effects of different environmental and operational factors on the PV performance: A comprehensive review. In Energy science and engineering (Vol. 10, Issue 2, pp. 656–675). Wiley. https://doi.org/10.1002/ese3.1043
18. Hussain, S., & AlAlili, A. (2017). A hybrid solar radiation modeling approach using wavelet multiresolution analysis and artificial neural networks. Applied Energy, 208, 540–550. https://doi.org/10.1016/j.apenergy.2017.09.100
19. Khan, W., Walker, S., & Zeiler, W. (2022). Improved solar photovoltaic energy generation forecast using deep learning-based ensemble stacking approach. Energy. https://doi.org/10.1016/j.energy.2021.122812
20. Ledmaoui, Y., el Maghraoui, A., el Aroussi, M., Saadane, R., Chebak, A., & Chehri, A. (2023). Forecasting solar energy production: A comparative study of machine learning algorithms. Energy Reports, 10, 1004–1012. https://doi.org/10.1016/j.egyr.2023.07.042
21. Lim, S. C., Huh, J. H., Hong, S. H., Park, C. Y., & Kim, J. C. (2022). Solar power forecasting using CNN-LSTM hybrid model. Energies. https://doi.org/10.3390/en15218233
22. Liu, C. H., Gu, J. C., & Yang, M. T. (2021). A simplified LSTM neural networks for one day-ahead solar power forecasting. IEEE Access, 9, 17174–17195. https://doi.org/10.1109/ACCESS.2021.3053638
23. Liu, H., Tian, H., Li, Y., & Zhang, L. (2015). Comparison of four Adaboost algorithm based artificial neural networks in wind speed predictions. Energy Conversion and Management, 92, 67–81. https://doi.org/10.1016/j.enconman.2014.12.053
24. Luo, X., Zhang, D., & Zhu, X. (2021). Deep learning based forecasting of photo voltaic power generation by incorporating domain knowledge. Energy. https://doi.org/10.1016/j.energy.2021.120240

25. Mekhilef, S., Saidur, R., & Kamalisarvestani, M. (2012). Effect of dust, humidity and air velocity on efficiency of photovoltaic cells. Renewable and Sustain able Energy Reviews, 16(5), 2920–2925. https://doi.org/10.1016/j.rser.2012.02.012
26. Mohammed, A., Adamu, A., Aghaegbunam, E. J., & Ukiri, M. (2023). Performance evaluation of the impacts of metrological parameters on crystalline and amorphous modules at Minna, Nigeria. Fundamental Journal of Sciences, 7(4), 36–46. https://doi.org/10.33003/fs-2023-0704-1928
27. Mohandes, B. M. A., El-Chaar, L., & Lamont, L. A. (2009). Application study of 500 W photovoltaic (PV) system in the UAE. Applied Solar Energy (english Transl Geliotekhnika), 45(4), 242–247. https://doi.org/10.3103/S0003701X09040057
28. Moretón, R., Lorenzo, E., Pinto, A., Munoz, J., & Narvarte, L. (2017). From broadband horizontal to effective in-plane irradiation: A review of modelling and derived uncertainty for PV yield prediction. Renewable and Sustainable Energy Reviews, 78, 886–903. https://doi.org/10.1016/j.rser.2017.05.020
29. Ndiaye, A., Charki, A., Kobi, A., Kébé, C. M. F., Ndiaye, P. A., & Sambou, V. (2013). Degradations of silicon photovoltaic modules: A literature review. Solar Energy, 96, 140–151. https://doi.org/10.1016/j.solener.2013.07.005
30. Pedregosa, F., Varoquaux, G., Gramfort, A., Michel, V., Thirion, B., Grisel, O., Blondel, M., Prettenhofer, P., Weiss, R., Dubourg, V., Vanderplas, J., Passos, A., Cournapeau, D., Brucher, M., Perrot, M., & Duchesnay, E. (2011). Scikit learn: Machine learning in Python. Journal of Machine Learning Research, 12, 2825–2830.
31. Persson, C., Bacher, P., Shiga, T., & Madsen, H. (2017). Multi-site solar power forecasting using gradient boosted regression trees. Solar Energy, 150, 423–436. https://doi.org/10.1016/j.solener.2017.04.066
32. Prasad, R., Ali, M., Kwan, P., & Khan, H. (2019). Designing a multi-stage multivariate empirical mode decomposition coupled with ant colony optimization and random forest model to forecast monthly solar radiation. Applied Energy, 236, 778–792. https://doi.org/10.1016/j.apenergy.2018.12.034
33. Rahimi, N., Park, S., Choi, W., Oh, B., Kim, S., Cho, Y. H., Ahn, S., Chong, C., Kim, D., Jin, C., & Lee, D. (2023). A comprehensive review on ensemble solar power forecasting algorithms. Journal of Electrical Engineering and Technology, 18(2), 719–733. https://doi.org/10.1007/s42835-23-01378-2
34. Rahman, M. M., Hasanuzzaman, M., & Rahim, N. A. (2017). Effects of operational conditions on the energy efficiency of photovoltaic modules operating in Malaysia. Journal of Cleaner Production, 143, 912–924. https://doi.org/10.1016/j.jclepro.2016.12.029

35. Raza, M. Q., Nadarajah, M., & Ekanayake, C. (2016). On recent advances in PV output power forecast. Solar Energy, 136, 125–144. https://doi.org/10.1016/j.solener.2016.06.073
36. Rodríguez, F., Martín, F., Fontán, L., & Galarza, A. (2021). Ensemble of machine learning and spatiotemporal parameters to forecast very short-term solar irradiation to compute photovoltaic generators' output power. Energy. https://doi.org/10.1016/j.energy.2021.120647
37. Said, S. A. M., Al-Aqeeli, N., & Walwil, H. M. (2015). The potential of using textured and anti-reflective coated glasses in minimizing dust fouling. Solar Energy, 113, 295–302. https://doi.org/10.1016/j.solener.2015.01.007
38. Said, S. A. M., Hassan, G., Walwil, H. M., & Al-Aqeeli, N. (2018). The effect of environmental factors and dust accumulation on photovoltaic modules and dust-accumulation mitigation strategies. Renewable and Sustainable Energy Reviews, 82, 743–760. https://doi.org/10.1016/j.rser.2017.09.042
39. Santbergen, R., Muthukumar, V. A., Valckenborg, R. M. E., van de Wall, W. J. A., Smets, A. H. M., & Zeman, M. (2017). Calculation of irradiance distribution on PV modules by combining sky and sensitivity maps. Solar Energy, 150, 49–54. https://doi.org/10.1016/j.solener.2017.04.036
40. Touati, F., Massoud, A., Hamad, J. A., & Saeed, S. A. (2013). Effects of environmental and climatic conditions on PV efficiency in Qatar. Renewable Energy and Power Quality Journal, 1(11), 262–267. https://doi.org/10.24084/repqj11.275
41. Verma, S., Mohapatra, S., Chowdhury, S., & Dwivedi, G. (2020). Cooling techniques of the PV module: A review. Mater Today Proc., 38, 253–258. https://doi.org/10.1016/j.matpr.2020.07.130
42. Wang, Y., Feng, B., Hua, Q. S., & Sun, L. (2021). Short-term solar power forecasting: A combined long short-term memory and Gaussian process regression method. Sustainability (switzerland). https://doi.org/10.3390/su13073665
43. Yang, D. (2019). On post-processing day-ahead NWP forecasts using Kalman fltering. Solar Energy, 182, 179–181. https://doi.org/10.1016/j.solener.2019.02.044
44. Zazoum, B. (2022). Solar photovoltaic power prediction using different machine learning methods. Energy Reports, 8, 19–25. https://doi.org/10.1016/j.egyr.2021.11.183.

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Weakly Nonlinear Modulation for Broader Bandwidth Capillary-Gravity Waves in Deep Water

Tanmoy Pal[1*] Sayanti Majumdar[2]
[1]Indian Institute of Engineering Science and Technology, Shibpur & Swami Vivekananda University, Barrackpore, India
[2]Modern English Academy, Barrackpore, India

***Corresponding Author:** tanmoypal@svu.ac.in

Abstract

This study explores weakly nonlinear modulation of capillary-gravity waves in deep water, focusing on the resulting broadening of bandwidth. By analyzing the interaction between capillary and gravity forces, we uncover how weak nonlinearity influences wave behavior, particularly in the context of wave packet formation and evolution. Employing analytical techniques, we derive a generalized modified nonlinear Schrödinger equation that captures the dynamics of these waves, highlighting the emergence of new frequency components through nonlinear interactions. Our findings indicate that in deep water, the balance between capillary and gravity effects leads to enhanced amplitude modulation, which significantly broadens the spectral bandwidth of wave packets. This behavior has important implications for various applications, including coastal engineering and marine navigation, where accurate predictions of wave characteristics are essential. The results not only deepen our understanding of capillary-gravity wave dynamics but also provide a foundation for future research into complex wave interactions under varying environmental conditions. Overall, this work contributes to the growing body of knowledge on nonlinear wave phenomena, emphasizing the relevance of weakly nonlinear modulation in shaping the behavior of capillary-gravity waves in deep-water settings.

Introduction

In the studies of the nonlinear evolution of finite depth of water waves, nonlinear Schrödinger equation (NLSE) is generally used as it can properly reflect the sideband instability, that is, the Benjamin-Feir instability. In general, capillary-gravity waves are generated by wind which produces a shear flow in the topmost layer of the water and as a result these waves move in the presence of vorticity. These waves play a momentous role in the development of wind waves, contribute partially to the ocean surface stress and therefore take part in ocean-sea momentum transfer. Proper representation of the surface stress is useful in modelling and predicting sea wave dynamics. The instability of finite amplitude capillary-gravity waves has been studied by many authors. Djordjevic and Redekopp [1] and Hogan [2] have investigated cubic nonlinear envelope equations for finite and infinite depths of water respectively and studied the sideband instability (Benjamin-Feir instability) of progressive capillary-gravity waves. Dhar and Das [3] have investigated the fourth-order nonlinear evolution equation (NLEE) for two surface capillary-gravity waves on deep water and stability analysis is then presented for two Stokes waves. Debsarma and Das [4] have also derived two coupled fourth-order NLEEs in deep water including the effect of thin thermocline for capillary-gravity waves. After reducing these two equations to a single equation in the case of oblique plane wave perturbation, they have studied the stability analysis for a uniform wave train. Although the stability analysis made from fourth-order NLSE gives excellent results compared to the third-order equation, the limitation in wave bandwidth severely restricts the applicability of third- and fourth-order Schrödinger equations for three-dimensional sea waves in two ways. First, the ocean wave spectra from the continental shelf are often bandwidth restricted but have bandwidths exceeding the above restriction. Second, these evolution equations have instability regions for a finite amplitude wave extending outside the narrow bandwidth constraint. Keeping this view, Trulsen and Dysthe [5] have derived a higher-order NLEE for the broader bandwidth surface gravity waves on deep water in which the wave bandwidth and nonlinearity have been considered as $O(\epsilon^{1/2})$ and $O(\epsilon)$ respectively. Following Trulsen and Dysthe [5], we take finite depth, deep water, and infinite depth as $(kh)^{-1}$ being $O(1), O(\epsilon)$ and 0 respectively.

According to Trulsen and Dysthe [5], one avenue of interest is to include some new linear terms to the fourth-order NLEE derived by Dysthe [6], which have increased considerably the resolution in spectral bandwidth. In this paper, we extend the analysis of Trulsen and Dysthe [5] to include the effect of capillarity. The objective and the novelty of this paper is to derive a new higher-order NLEE for a broader bandwidth and to develop a weakly nonlinear theory of the periodic capillary-gravity waves on finite depth of water.

The Governing Equations and The Fourth-order Evolution Equation

The set of equations governing the surface capillary-gravity waves on inviscid, incompressible and irrotational fluid with uniform depth h is given by

$$\nabla^2\phi = 0 \text{ in} -h < z < \zeta(x,y,t) \quad (1)$$

$$\phi_z - \zeta_t = \phi_x\zeta_x + \phi_y\zeta_y \text{ at } z = \zeta \quad (2)$$

$$\phi_t + \zeta = -\frac{1}{2}(\nabla\phi)^2 + \kappa\frac{(\zeta_x^2\zeta_{yy}+\zeta_y^2\zeta_{xx}-2\zeta_x\zeta_y\zeta_{xy}+\zeta_{xx}+\zeta_{yy})}{(1+\zeta_x^2+\zeta_y^2)^{\frac{3}{2}}} \text{ at } z = \zeta \quad (3)$$

Also $\phi_z = 0$, at $z = -h$, (4)

where $\phi(x,y,z,t)$ is the velocity potential of waves, $\zeta(x,y,t)$ is the undulating free surface, ρ is the density of fluid and $\nabla \equiv \left(\frac{\partial}{\partial x},\frac{\partial}{\partial y},\frac{\partial}{\partial z}\right)$. The above equations have been made dimensionless by the following transformations

$$\tilde{\phi} = \sqrt{\frac{k_0^3}{g}}\phi, \tilde{\zeta} = k_0\zeta, (\tilde{x},\tilde{y},\tilde{z}) = (k_0x, k_0y, k_0z), \tilde{t} = \omega t, \kappa = \frac{Tk_0^2}{\rho g},$$

where k_0 is some characteristic wavenumber, g is the gravitational acceleration and T is the surface tension coefficient of the bulk fluid. In subsequent analysis, all these dimensionless quantities will be written with their tilde deleted.

The solutions of the above-mentioned equations can be expressed as

$$B = \bar{B} + \sum_{p=1}^{\infty}\left[B_p exp\{(ip(kx-\omega t))\} + c.c.\right] , \quad (5)$$

where B indicates ϕ, ζ; $c.c.$ means complex conjugate and k,ω are the wavenumber and frequency of the primary wave respectively. Here, the slow drift $\bar{\phi}$ and set down $\bar{\zeta}$ as well as the harmonic amplitudes ϕ_p, ζ_p $(p = 1,2,\ldots)$ and their complex conjugatesare functions of the slow modulation variables $\epsilon x, \epsilon y$ and ϵt, where ϵ is a slow ordering parameter. Again, $\bar{\phi}$ depends on the slow variable ϵz, while ϕ_p $(p = 1,2,\ldots)$ and their complex conjugates are the function of z. We consider the fourth-order NLEE for narrow bandwidth when the motion is weakly nonlinear, so that $0 < \epsilon \ll 1$ subject to the assumption as follows

$$k_0a = O(\epsilon), \frac{|\nabla\boldsymbol{k}|}{k_0} = O(\epsilon), (k_0h)^{-1} = O(\epsilon)$$

The linear dispersion relation with $l = 0$ is given by

$$f(\omega,k,l) = \omega^2 - \sqrt{k^2+l^2}\{1+\kappa(k^2+l^2)\} = 0 ,$$

whereω, k represent the carrier frequency and wave number respectively.

By a standard procedure (Dhar and Das [7]) we obtain the fourth-order coupled NLEEs for the free surface elevation ζ, where $\zeta = \zeta_{11} + \epsilon\zeta_{12}$, and $\bar{\phi}$ as follows

$$i\left(\frac{\partial\zeta}{\partial\tau} + c_g\frac{\partial\zeta}{\partial x}\right) - \gamma_1\frac{\partial^2\zeta}{\partial x^2} + \gamma_2\frac{\partial^2\zeta}{\partial y^2} + i\left(\gamma_3\frac{\partial^3\zeta}{\partial x^3} + \gamma_4\frac{\partial^3\zeta}{\partial x\partial y^2}\right) = \mu_1|\zeta|^2\zeta^* + i\left(\mu_2|\zeta|^2\frac{\partial\zeta}{\partial x} + \mu_3\zeta^2\frac{\partial\zeta^*}{\partial x}\right) + \zeta\frac{\partial\bar{\phi}}{\partial x} \quad (6)$$

$$\nabla^2\bar{\phi} = 0 \text{ for } -h < z < 0 \quad (7)$$

$$\frac{\partial\bar{\phi}}{\partial z} = 2\frac{\partial}{\partial x}(|\zeta|^2) \text{ for } z = 0 \quad (8)$$

$$\frac{\partial\bar{\phi}}{\partial z} = 0 \text{ for } z = -h \quad (9)$$

For $\kappa = 0$, the equation (6) is identical to an equation (10) of Trulsen and Dysthe [5].

Typically, one assumes that the wave steepness and the bandwidth are of the identical order of magnitude $O(\epsilon)$, for which both the nonlinear and dispersive effects balance at the fourth order $O(\epsilon^4)$.

Stability Analysis

A solution for the uniform wave train of the NLEE is given by

$$\zeta = \frac{\zeta_0}{2}e^{-i\mu_1\zeta_0^2 t/4}, \bar{\phi} = \phi_0,$$

whereζ_0, ϕ_0 are real constants.

We assume the perturbations on this solution as follows

$$\zeta = \frac{\zeta_0}{2}(1+\zeta')e^{i(\theta' - \mu_1\zeta_0^2 t/4)},\ \bar{\phi} = \phi_0(1+\phi'), \quad (10)$$

whereζ', θ' are infinitesimal perturbations of the amplitude and phase respectively and ϕ' is a real small perturbation of $\bar{\phi}$. Inserting (10) in equation (6) we get the two linear equations in $\zeta'$and θ'. Now we take the plane wave solution of the above two equations given by

$$\begin{pmatrix}\zeta'\\ \theta'\end{pmatrix} = \begin{pmatrix}\hat{\zeta}\\ \hat{\theta}\end{pmatrix}e^{i(\lambda x + \mu y - \Omega t)} + c.c.$$

$$\phi' = \hat{\phi}\left\{e^{i(\lambda x + \mu y - \Omega t)} + c.c.\right\}\frac{\cos\bar{k}(z+h)}{\cosh(\bar{k}h)},\ \bar{k}^2 = \lambda^2 + \mu^2$$

The perturbed wave numbers λ, μ and the perturbed frequency Ω satisfy the following nonlinear dispersion relation

$$\left\{\bar{S_1} + \frac{(\mu_2+\mu_3)}{4}\zeta_0^2\lambda\right\}\left\{\bar{S_1} + \frac{(\mu_2-\mu_3)}{4}\zeta_0^2\lambda\right\} = \bar{S_2}\left\{\bar{S_2} - \frac{\mu_1}{2}\zeta_0^2 + \frac{\lambda^2\zeta_0^2}{\bar{k}\tanh(\bar{k}h)}\right\}, \quad (11)$$

where$\bar{S_1} = \Omega - c_g\lambda + \gamma_3\lambda^3 + \gamma_4\lambda\mu^2$ and $\bar{S_2} = \gamma_1\lambda^2 - \gamma_2\mu^2$ and c_g is the group velocity of the carrier wave.

The solution of (11) is given by

$$\bar{S}_1 = -\frac{\mu_2}{4}\zeta_0^2\lambda \pm \sqrt{\bar{S}_2\left\{\bar{S}_2 - \frac{\mu_1}{2}\zeta_0^2 + \frac{\lambda^2\zeta_0^2}{\bar{k}\tanh(\bar{k}h)}\right\}} \tag{12}$$

From (12) the instability occurs if

$$\bar{S}_2\left\{\bar{S}_2 - \frac{\mu_1}{2}\zeta_0^2 + \frac{\lambda^2\zeta_0^2}{\bar{k}\tanh(\bar{k}h)}\right\} < 0 \tag{13}$$

If the condition (13) is satisfied, the perturbed frequency Ω will be a complex valued and the growth rate of instability represented by the imaginary part Ω_i of Ω becomes

$$\Omega_i = \sqrt{(\gamma_1\lambda^2 - \gamma_2\mu^2)\left(\frac{\mu_1}{2}\zeta_0^2 - \gamma_1\lambda^2 + \gamma_2\mu^2 - \frac{\lambda^2\zeta_0^2}{\bar{k}\tanh(\bar{k}h)}\right)}. \tag{14}$$

Higher-order Evolution Equation for Broader Bandwidth

To obtain a better resolution in bandwidth, following Trulsen and Dysthe [5], we take the following assumptions

$$k_0 a = O(\epsilon), \frac{|\nabla \boldsymbol{k}|}{k_0} = O\left(\epsilon^{1/2}\right), (k_0 h)^{-1} = O\left(\epsilon^{1/2}\right)$$

We use here the same harmonic expansions (5) for the velocity potential ϕ and the surface elevation ζ. In this case $\bar{\phi}, \bar{\zeta}, \phi_p, \zeta_p\ (p = 1, 2, \dots)$ are functions of the new slightly faster modulation variables $\epsilon^{1/2}t$and $\epsilon^{1/2}x$, $\epsilon^{1/2}y$ and also $\bar{\phi}$ depends on the new slightly faster variable $\epsilon^{1/2}z$.

Now we take the following perturbation expansions

$E_1 = \sum_{p=1}^{\infty}\epsilon^{p/2}E_{1p}\ ,\ E_2 = \sum_{p=2}^{\infty}\epsilon^{p/2}E_{2p},$

whereE_j stands for B_j and ζ_j , $B_j = \left(\phi_j\right)_{z=0}, j = 1,2.$

Herein, we keep the same accuracy in nonlinearity as in equation (6) and it is to be noted that as all the fourth-order contributions to this equation are not quartically nonlinear, it is sufficient to consider the new evolution equation for broader bandwidth only up to $O\left(\epsilon^{7/2}\right)$.

Computing the perturbation analysis as in Dhar and Das [7], we obtain eventually the coupled NLEEs in terms of ζ and $\bar{\phi}$ for broader bandwidth as follows

$$i\left(\frac{\partial\zeta}{\partial\tau} + c_g\frac{\partial\zeta}{\partial x}\right) - \gamma_1\frac{\partial^2\zeta}{\partial x^2} + \gamma_2\frac{\partial^2\zeta}{\partial y^2} + i\left(\gamma_3\frac{\partial^3\zeta}{\partial x^3} + \gamma_4\frac{\partial^3\zeta}{\partial x\partial y^2}\right) + \gamma_5\frac{\partial^4\zeta}{\partial x^4} + \gamma_6\frac{\partial^4\zeta}{\partial x^2\partial y^2} + \gamma_7\frac{\partial^4\zeta}{\partial y^4} + i\left(\gamma_8\frac{\partial^5\zeta}{\partial x^5} + \gamma_9\frac{\partial^5\zeta}{\partial x^3\partial y^2} + \gamma_{10}\frac{\partial^5\zeta}{\partial x\partial y^4}\right) = \mu_1|\zeta|^2\zeta^* + i\left(\mu_2|\zeta|^2\frac{\partial\zeta}{\partial x} + \mu_3\zeta^2\frac{\partial\zeta^*}{\partial x}\right) + \zeta\frac{\partial\bar{\phi}}{\partial x} \tag{15}$$

$$\nabla^2\bar{\phi} = 0 \text{ for } -h < z < 0 \tag{16}$$

$$\frac{\partial\bar{\phi}}{\partial z} = 2\frac{\partial}{\partial x}(|\zeta|^2) \text{ for } z = 0 \tag{17}$$

$$\frac{\partial\bar{\phi}}{\partial z} = 0 \text{ for } z = -h, \tag{18}$$

where the coefficients are given in Appendix.

In the new NLSE for broader bandwidth, we have assumed that the wave steepness is of order $O(\epsilon)$, while the wave bandwidth is of order $O\left(\epsilon^{1/2}\right)$ for which the nonlinear and the dispersive effects balance at the order $O\left(\epsilon^{7/2}\right)$.

In the absence of capillarity, the equation (15) reduces to an equation (21) of Trulsen and Dysthe [5].

Proceeding as in section 3, we obtain the nonlinear dispersion relation as follows

$$\left\{R_1+\frac{(\mu_2+\mu_3)}{4}\zeta_0^2\lambda\right\}\left\{R_1+\frac{(\mu_2-\mu_3)}{4}\zeta_0^2\lambda\right\}=R_2\left\{R_2-\frac{\mu_1}{2}\zeta_0^2+\frac{\lambda^2\zeta_0^2}{\bar{k}\tanh(\bar{k}h)}\right\}, \quad (19)$$

where

$$R_1=\Omega-c_g\lambda+\gamma_3\lambda^3+\gamma_4\lambda\mu^2-\gamma_8\lambda^5-\gamma_9\lambda^3\mu^2-\gamma_{10}\lambda\mu^4, \quad (20)$$

$$R_2=\gamma_1\lambda^2-\gamma_2\mu^2+\gamma_5\lambda^4+\gamma_6\lambda^2\mu^2+\gamma_7\mu^4.$$

The solution of (19) is given by

$$R_1=-\frac{\mu_2}{4}\zeta_0^2\lambda\pm\sqrt{R_2\left\{R_2-\frac{\mu_1}{2}\zeta_0^2+\frac{\lambda^2\zeta_0^2}{\bar{k}\tanh(\bar{k}h)}\right\}} \quad (21)$$

Using (20) the equation (19) can be expressed as

$$\Omega=c_g\lambda-\gamma_3\lambda^3-\gamma_4\lambda\mu^2+\gamma_8\lambda^5+\gamma_9\lambda^3\mu^2+\gamma_{10}\lambda\mu^4-\frac{\mu_2}{4}\zeta_0^2\lambda\pm\sqrt{R_2\left\{R_2-\frac{\mu_1}{2}\zeta_0^2+\frac{\lambda^2\zeta_0^2}{\bar{k}\tanh(\bar{k}h)}\right\}} \quad (22)$$

If we set $\kappa=0$, then the equation (22) reduces to an equation equivalent to equation (25) of Trulsen and Dysthe [5].

It follows from (22) that for instability we have

$$R_2\left\{R_2-\frac{\mu_1}{2}\zeta_0^2+\frac{\lambda^2\zeta_0^2}{\bar{k}\tanh(\bar{k}h)}\right\}<0 \quad (23)$$

The instability growth rate Ω_i, which is the imaginary part of the perturbed frequency Ω, is given by

$$\Omega_i=\sqrt{R_2\left(\frac{\mu_1}{2}\zeta_0^2-R_2-\frac{\lambda^2\zeta_0^2}{\bar{k}\tanh(\bar{k}h)}\right)} \quad (24)$$

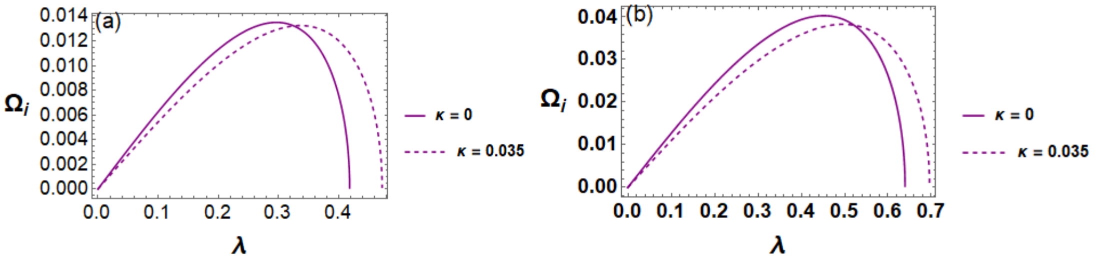

Fig-1: Plot of growth rate of instability Ω_i against λ for $h = 6$ and two values of ; (a) $\zeta_0 = 0.2$, (b) $\zeta_0 = 0.4$

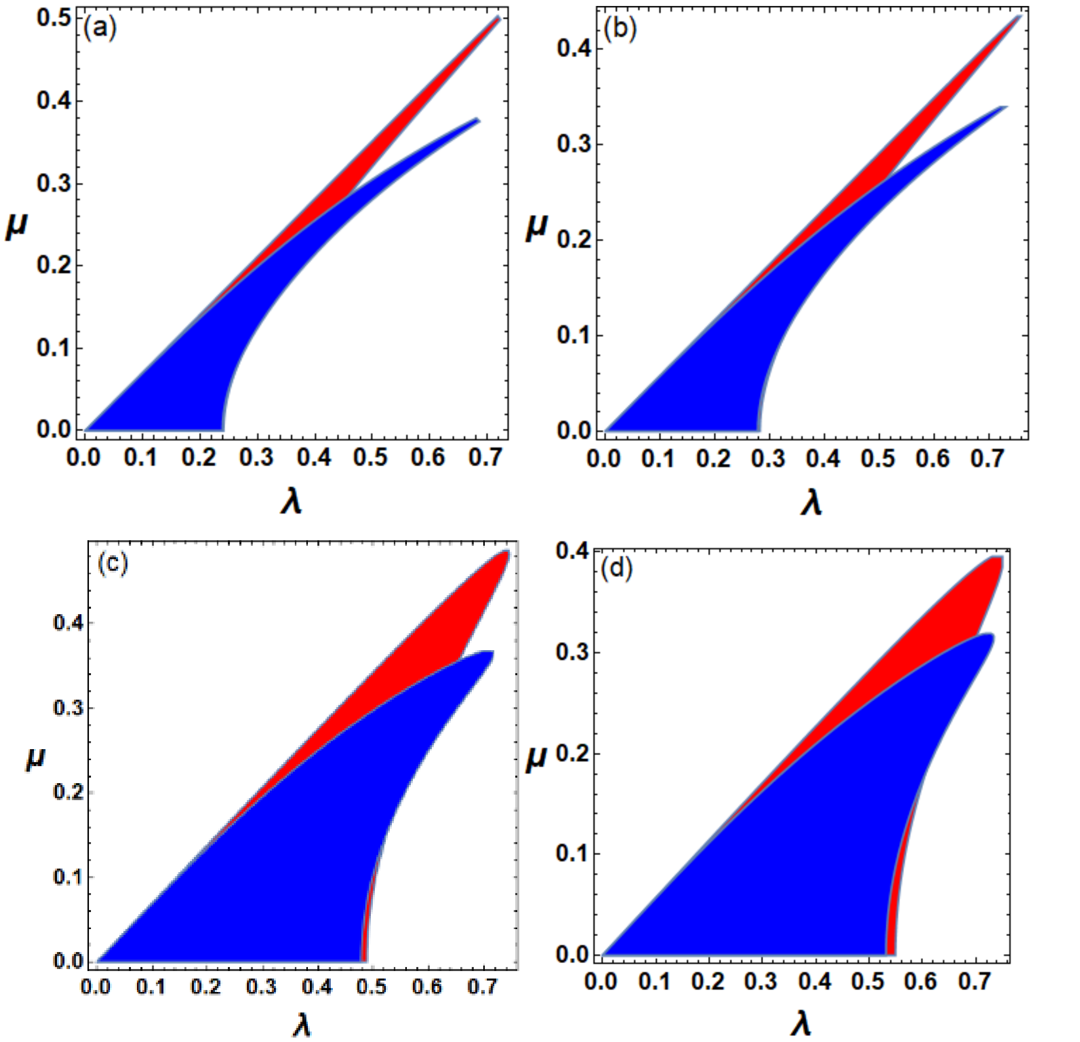

Fig-2: The (λ, μ) instability diagrams for $h = 6$; (a) $\kappa = 0, \zeta_0 = 0.1$, (b) $\kappa = 0.035, \zeta_0 = 0.1$, (c) $\kappa = 0, \zeta_0 = 0.25$, (d) $\kappa = 0.035, \zeta_0 = 0.25$; Blue regions corresponding to new broader-banded result and red regions to narrow-banded result.

The plot of the growth rate of instability (GRI) Ω_i given by (24) against λ for a broader bandwidth is shown in Fig. 1 for $h = 6$ and different values of κ and wave steepness ζ_0. It is seen that the effect of capillarity is to reduce the growth rate giving a stabilizing influence. The GRI increases considerably with the increase of wave steepness.

From the instability condition (23) the modulational instability regions in the (λ, μ) plane are plotted in Fig. 2 and for two values of $\zeta_0 = 0.1, 0.25$ and $\kappa = 0, 0.035$. Fig. 2(a) for $\kappa = 0, \zeta_0 = 0.1$ is identical with the figure obtained by Trulsen and Dysthe [5] in figure 5. Thus, we can verify that this limiting case is reproduced exactly. It is observed that both the capillarity and the wave steepness modify significantly the instability regions.

Conclusion

In conclusion, our investigation into weakly nonlinear modulation of capillary-gravity waves in deep water has revealed significant insights into the mechanisms that facilitate bandwidth broadening. The interaction between capillary and gravity forces in this regime has been shown to enhance wave packet dynamics, leading to the generation of new frequency components and intricate modulation patterns. By deriving a generalized nonlinear Schrödinger equation, we have effectively captured these complex dynamics, demonstrating that weak nonlinearity plays a crucial role in determining wave evolution. The results indicate that in deep-water environments, the delicate balance between capillary and gravity influences not only the stability of wave packets but also their spectral characteristics. This understanding is vital for practical applications, particularly in coastal engineering and marine navigation, where the accurate prediction of wave behavior is essential for safety and infrastructure design. Moreover, our findings lay the groundwork for further research into nonlinear wave phenomena, inviting exploration of additional factors such as environmental variability and wave interactions. Overall, this study enhances our comprehension of capillary-gravity wave dynamics and underscores the importance of weakly nonlinear effects in shaping wave behavior. As we continue to unravel the complexities of nonlinear interactions, this work contributes valuable knowledge that can inform both theoretical investigations and practical applications in oceanography and coastal management, ultimately fostering improved predictive capabilities in marine environments.

Appendix

$$\gamma_1 = \frac{B}{2\sigma f_\sigma^2(1+\kappa)}, \gamma_2 = \frac{1+3\kappa}{\sigma f_\sigma^2}, \gamma_3 = \frac{2AB-\kappa f_\sigma^4}{2\sigma f_\sigma^4(1+\kappa)}, \gamma_4 = \frac{(1-3\kappa)f_\sigma^2-2(1+3\kappa)A}{4\sigma f_\sigma^2(1+\kappa)},$$

$$\gamma_5 = \frac{A^4+4A^2B-6A^2\kappa f_\sigma^2-2A\kappa f_\sigma^4+9\kappa^2 f_\sigma^2}{2\sigma f_\sigma^6(1+\kappa)}, \gamma_6 = \frac{(1-3\kappa)Af_\sigma^2-(1+3\kappa)\left(2A^2+B\right)-\{(f_\sigma\}^4/2)}{2\sigma f_\sigma^4(1+\kappa)},$$

$$\gamma_7 = \frac{2(1+3\kappa)^2+(1-3\kappa)f_\sigma^2}{16\sigma f_\sigma^2(1+\kappa)}, \gamma_8 = \frac{-2AB\left(4A^2+3B\right)+4B\kappa f_\sigma^4+4uA\kappa f_\sigma^5+2\{f_k^2-\left(u^2-3\kappa\right)f_\sigma^2\}\kappa f_\sigma^4}{2\sigma f_\sigma^8(1+\kappa)},$$

$\gamma_9 = \frac{(1+3\kappa)(4A^3+6AB-\kappa f_\sigma^4)-(1-3\kappa)(2A^2 f_\sigma^2+Bh_\sigma^2)+Af_\sigma^4-\{(f_\sigma\}^6/2)}{2\sigma f_\sigma^6(1+\kappa)}$,

$\gamma_{10} = \frac{-2(1-3\kappa)Af_\sigma^2-12(1+3\kappa)^2A+4(1+3\kappa)(1-3\kappa)f_\sigma^2+3(1-\kappa)f_\sigma^4}{16\sigma f_\sigma^4(1+\kappa)}$, $\mu_1 = \frac{1}{\sigma f_\sigma^2}\left\{\frac{4(1+\kappa)(2-\kappa)}{1-2\kappa} - 3\kappa\right\}$

$\mu_2 = \frac{3(4\kappa^4+4\kappa^3-9\kappa^2+\kappa-8)}{\sigma f_\sigma^2(1+\kappa)(1-2\kappa)^2}$, $\mu_3 = \frac{(2\kappa^2+\kappa+8)(1-\kappa)}{2\sigma f_\sigma^2(1+\kappa)(1-2\kappa)}$, $A = f_k, B = {f_k}^2 - 3\kappa f_\sigma^2, f_k = \frac{\partial f}{\partial k}, f_\sigma = \frac{\partial f}{\partial \sigma}$.

References

1. Djordjevic, V. D. and Redekopp, L. G., “On two-dimensional packets of capillary-gravity waves”, Journal of Fluid Mechanics 79(4), 703-714 (1977).
2. Hogan, S. J., “The fourth-order evolution equation for deep-water gravity-capillary waves”, Proc. R. Soc. Lond. A402, 359–372 (1985).
3. Dhar, A. K. and Das, K. P., “Effect of capillarity on fourth-order nonlinear evolution equations for two Stokes wave trains in deep water”, J. Indian Inst. Sci. 73, 579 (1993).
4. Debsarma, S. and Das, K. P., “Fourth order nonlinear evolution equations for gravity-capillary waves in the presence of a thin thermocline in deep water”, The Anziam Journal 43(4), 513-524 (2002).
5. Trulsen, K. and Dysthe, K. B., “A modified nonlinear Schrödinger equation for broader bandwidth gravity waves on deep water”, Wave Motion 24(3), 281-289 (1996).
6. K. B. Dysthe, “Note on a modification to the nonlinear Schrödinger equation for application to deep water waves”, Proc. R. Soc. Lond. A 369, 105–114, (1979).
7. Dhar, A. K. and Das, K. P., “A fourth-order evolution equation for deep water surface gravity waves in the presence of wind blowing over water”, Physics of Fluids A: Fluid Dynamics 2, no. 5,778–783 (1990).
8. McLean, J. W., Ma, Y. C., Martin, D. U., Saffman, P. G. and Yuen, H. C. “Three-dimensional instability of finite-amplitude water waves”, Phys. Rev. Lett. 46: 817–820 (1981).

Nomenclature

h	Uniform depth of the fluid
ϕ	Velocity potential of capillary-gravity waves
ζ	Undulating free surface
ρ	Density of fluid
k_0	Characteristic wave number

g	Gravitational acceleration
T	Surface tension coefficient of the bulkfluid
ϵ	Slow ordering parameter
ω	Carrier frequency
k	Carrier wave number
c_g	Group velocity
ζ_0	Wave steepness
(λ, μ)	Perturbed wave numbers
Ω	Perturbed frequency
Ω_i	Growth rate of instability.

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Evaluating the Role of Sustainable R&D in Achieving Net-Zero Carbon Emissions by 2050

Sangita Bose*
Swami Vivekananda University, Kolkata, West Bengal, India

***Corresponding Author:** sangitab@svu.ac.in

Abstract

The global climate crisis necessitates immediate and transformative actions across all sectors. Sustainable research and development (R&D) plays a pivotal role in this transformation, driving the innovation needed to achieve net-zero carbon emissions by 2050. This paper evaluates the critical role of sustainable R&D in sectors such as energy, transportation, and manufacturing, examining how breakthroughs in technology, policy frameworks, and public-private partnerships contribute to achieving climate goals. The study also highlights the need for increased investments in sustainable R&D and the integration of sustainability principles across all stages of the innovation process.

Introduction

The ambition to achieve net-zero carbon emissions by 2050 is now central to global climate policies. Achieving this target requires transformative shifts in how societies produce and consume energy, manage natural resources, and mitigate the negative impacts of industrial activities. Sustainable R&D has a critical role in this transition, serving as the engine for innovation in green technologies and enabling practices that reduce carbon footprints while supporting economic growth. This paper examines the various dimensions of sustainable R&D, its role in different sectors, and the systemic challenges and opportunities it faces.

Role of Sustainable R&D in Key Sectors

- **Energy Sector**

The energy sector is a major contributor to global greenhouse gas emissions, making it a key focus for sustainable R&D. Investment in renewable energy technologies, including solar, wind, and hydropower, is central to decarbonizing the energy supply [1]. Advances in energy storage, grid management, and smart grid technologies also play an important role in improving the efficiency and reliability of renewable energy systems [2].

The development of green hydrogen, carbon capture and storage (CCS), and next-generation nuclear technologies are pivotal to achieving long-term decarbonization [3]. Sustainable R&D in these areas ensures that these technologies become commercially viable and scalable.

- **Transportation Sector**

Transportation accounts for nearly a quarter of global CO2 emissions. Electrification of transport, powered by renewable energy, is crucial to reducing emissions from this sector. Sustainable R&D in battery technologies, charging infrastructure, and electric vehicle (EV) design has made significant strides in recent years [4]. Furthermore, the development of alternative fuels, such as biofuels and synthetic fuels, provides additional pathways for decarbonization, particularly in aviation and shipping, where electrification remains a challenge [5].

- **Manufacturing and Industry**

The manufacturing sector faces complex challenges in achieving net-zero emissions due to its heavy reliance on high-energy processes. Sustainable R&D efforts in this area focus on energy efficiency, the adoption of circular economy principles, and the development of low-carbon materials [6]. Innovations in carbon-neutral steel and cement production, as well as the application of digital technologies like AI and IoT for process optimization, hold significant potential for reducing emissions in industrial processes [7].

Public-Private Partnerships in Sustainable R&D

Public-private partnerships (PPPs) have proven to be a powerful mechanism for driving sustainable R&D. Governments provide the regulatory frameworks, incentives, and financial support needed to de-risk R&D investments, while private companies contribute expertise, infrastructure, and market access [8]. Successful PPPs, such as those between governments and major automakers in developing electric vehicles, demonstrate the impact of collaboration on accelerating innovation [9].

Policy and Regulatory Support for Sustainable R&D

Governments have a key role in creating the right environment for sustainable R&D. Policy interventions such as subsidies, tax credits, and direct funding for research institutions and private companies are essential for driving innovation [10]. Additionally, the establishment of clear carbon pricing mechanisms, emissions regulations, and sustainability standards can incentivize investment in green technologies [11].

The European Union's Green Deal, which includes significant funding for sustainable R&D, is an example of policy support that aligns economic growth with sustainability objectives [12]. Similarly, initiatives like the U.S. Advanced Research Projects Agency-Energy (ARPA-E) focus on supporting high-risk, high-reward research projects aimed at solving critical energy challenges [13].

Challenges and Opportunities

- **Funding and Investment Gaps**

Despite growing recognition of the importance of sustainable R&D, funding remains a challenge, especially in regions with limited public investment capacity. Bridging the gap between early-stage innovation and commercialization is critical to ensuring that breakthrough technologies reach the market [14]. Enhanced collaboration between financial institutions, governments, and industries will be required to address these funding challenges.

- **Technological Uncertainties**

The pace of technological advancement in sustainable R&D can be unpredictable, and some innovations may fail to scale up to a commercially viable level. It is crucial to manage these uncertainties through diversified R&D portfolios and adaptive regulatory frameworks that allow for experimentation and iterative development [15].

- **Global Disparities**

Global disparities in R&D capacity and resources could hinder the equitable distribution of sustainable technologies. Low- and middle-income countries may struggle to access the benefits of sustainable R&D, which could widen the gap between developed and developing nations in their ability to achieve net-zero emissions [16]. International cooperation and technology transfer mechanisms are necessary to address these challenges.

Conclusion

Sustainable R&D is indispensable for achieving the ambitious goal of net-zero carbon emissions by 2050. Investments in green technologies across energy, transportation, and manufacturing sectors are already showing promise, but much more needs to be done. Public-private partnerships, supportive policy frameworks, and increased funding are key enablers of sustainable R&D. As the global community pushes toward a low-carbon future, sustainable R&D will continue to be a driving force in shaping the innovations and solutions needed to mitigate climate change while supporting economic development.

References

1. IRENA. (2021). *Renewable Capacity Statistics 2021*. International Renewable Energy Agency.
2. U.S. Department of Energy. (2020). *Energy Storage Grand Challenge: Energy Storage Market Report*.
3. IEA. (2021). *The Role of Hydrogen in Achieving Net-Zero Emissions*.
4. International Energy Agency. (2020). *Global EV Outlook 2020*.
5. Suresh, P., et al. (2022). "Biofuels: A Sustainable Fuel Source for Aviation and Shipping Industries." *Journal of Clean Energy*, 12(3), 88-104.
6. Ellen MacArthur Foundation. (2021). *The Circular Economy: A Transformative Approach to Sustainability*.
7. Worrell, E., et al. (2019). "Energy Efficiency and Carbon Emissions Reduction Potentials in the Steel and Cement Industries." *Journal of Industrial Ecology*, 23(2), 345-357.
8. OECD. (2021). *Public-Private Partnerships for Sustainable Development*.
9. McKinsey & Company. (2021). "The Future of Electric Vehicles and the Role of Partnerships in Scaling Innovation."
10. UNFCCC. (2020). *National Climate Action Plans and Sustainable Development*.
11. European Commission. (2020). *European Green Deal: Policy Measures for a Sustainable Future*.
12. European Union. (2020). *Green Deal: A Strategy for Europe's Sustainable Future*.
13. U.S. Department of Energy. (2021). *ARPA-E Annual Report 2021*.
14. UNEP. (2020). *Sustainable Investment Report*.
15. Bui, M., et al. (2018). "Carbon Capture and Storage: Technological Challenges and Future Opportunities." *Energy Policy*, 122, 225-235.
16. World Bank. (2021). *Bridging the Global Technology Gap for Sustainable Development*.

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25 The Impact of Policy and Regulation on Sustainable R&D: A Comparative Analysis Across Key Industries

Diganta Bhattacharyya*
Swami Vivekananda University, Kolkata, Pin-700121, West Bengal India

***Corresponding Author:** digantab@svu.ac.in

Abstract

This paper examines the impact of policy and regulation on sustainable research and development (R&D) across key industries, focusing on how government initiatives, laws, and regulations shape the direction and effectiveness of sustainability-oriented innovations. A comparative analysis is conducted across energy, transportation, healthcare, and manufacturing industries. Findings suggest that while policy frameworks significantly influence R&D activities in terms of resource allocation and innovation goals, the effectiveness varies by sector due to differing regulatory landscapes and market dynamics. The study concludes with recommendations for policymakers on fostering a more conducive environment for sustainable R&D across industries.

Introduction

Sustainable research and development (R&D) has become a focal point for industries worldwide as environmental concerns and resource scarcity intensify. Governments and regulatory bodies have responded by instituting policies aimed at promoting sustainability, including energy conservation, waste reduction, and the transition to renewable energy sources. These policies, however, differ widely across industries, resulting in varied impacts on sustainable R&D efforts. This paper provides a comparative analysis of the effect of policy and regulation on sustainable R&D across four key sectors: energy, transportation, healthcare, and manufacturing.

Literature Review

Sustainable R&D is inherently multidisciplinary, integrating engineering, environmental science, and economics. The role of policy in shaping R&D activities has been discussed in various contexts. For example, Grubb et al. (2018) emphasized that government policies can accelerate innovation in sustainable technologies by providing financial incentives and establishing market regulations. Similarly, regulatory frameworks such as the Paris Agreement have been instrumental in directing energy industries toward sustainable practices【1】.

The role of regulation is equally crucial in sectors like healthcare and manufacturing, where sustainability goes beyond environmental concerns to include the efficient use of resources and reduction of toxic emissions【2】. In transportation, policies aimed at reducing carbon emissions have spurred significant investment in electric vehicle (EV) technologies and alternative fuels【3】.

Methodology

This study adopts a comparative analysis framework to assess the impact of policy and regulation on sustainable R&D. The focus is on the energy, transportation, healthcare, and manufacturing sectors due to their differing levels of regulation and innovation intensity. Data were collected from academic journals, industry reports, and government publications. Key performance indicators (KPIs) such as investment in R&D, patent filings, and market adoption of sustainable technologies were analyzed across these sectors.

Comparative Analysis of Policy Impact on Sustainable R&D

- **Energy Sector**

The energy sector is one of the most heavily regulated industries globally, particularly in the area of renewable energy. Policies such as the Renewable Energy Directive in Europe and the Clean Power Plan in the United States have spurred investments in sustainable technologies like solar, wind, and bioenergy【4】. However, the sector faces challenges due to regulatory uncertainty, which can deter long-term investments in R&D. Subsidies, tax incentives, and carbon pricing have been effective in promoting R&D, but inconsistent policy signals can negatively affect the sustainability trajectory.

- **Transportation Sector**

The transportation industry has seen a significant shift towards sustainability, driven largely by regulations aimed at reducing greenhouse gas (GHG) emissions. The Corporate Average Fuel Economy (CAFE) standards in the U.S. and the European Union's vehicle emissions regulations have led to major advancements in electric vehicle (EV) technologies and alternative fuel research【5】. Despite this progress, the effectiveness of policies in driving R&D varies due to differences in regulatory stringency and market dynamics across regions【6】.

- **Healthcare Sector**

Sustainability in healthcare primarily focuses on waste reduction, energy efficiency, and the use of green technologies. Regulatory bodies such as the U.S. Food and Drug Administration (FDA) and the European Medicines Agency (EMA) have started incorporating sustainability considerations into their guidelines, particularly in the context of pharmaceutical development and medical devices【7】. However, the regulatory focus on patient safety often conflicts with sustainability goals, leading to slower adoption of green practices in R&D【8】.

- **Manufacturing Sector**

The manufacturing industry has experienced regulatory pressure to adopt sustainable practices, particularly in reducing emissions and waste. Regulations like the EU's Waste Electrical and Electronic Equipment (WEEE) Directive and the U.S. Clean Air Act have been effective in pushing companies toward sustainable R&D【9】. However, the cost of compliance with these regulations can sometimes limit R&D investments, particularly for small and medium-sized enterprises (SMEs)【10】.

- **Discussion**

The analysis highlights the varied impact of policy and regulation on sustainable R&D across different industries. The energy sector benefits significantly from direct government incentives and international agreements, which provide clear direction for R&D efforts. In contrast, the healthcare sector faces regulatory hurdles that can stifle innovation due to stringent safety requirements.

The transportation and manufacturing sectors fall somewhere in between, with regulations driving significant R&D efforts, particularly in the development of greener technologies and processes. However, the success of these efforts is contingent upon the alignment of policy frameworks with market demands and the flexibility of regulations to adapt to technological advancements.

Conclusion

The impact of policy and regulation on sustainable R&D varies significantly across industries. Policymakers need to create a balanced regulatory environment that promotes innovation while maintaining flexibility to accommodate industry-specific challenges. For the energy and transportation sectors, continued support for sustainable technologies through subsidies and emission reduction targets is crucial. In healthcare, regulatory reforms should encourage the integration of sustainability into R&D without compromising patient safety. Finally, in manufacturing, easing regulatory burdens on SMEs could foster more robust investments in sustainable innovation.

Recommendations

- **Energy Sector**: Strengthen policy coherence and reduce regulatory uncertainty to support long-term investments in sustainable R&D.
- **Transportation Sector**: Introduce more stringent emissions standards globally to ensure consistent progress in green vehicle technologies.
- **Healthcare Sector**: Encourage regulatory bodies to adopt more flexible guidelines that promote sustainable practices without compromising safety.
- **Manufacturing Sector**: Provide financial incentives for SMEs to invest in sustainable R&D and streamline compliance processes.

References

1. Grubb, M., Hourcade, J.C., & Neuhoff, K. (2018). *Innovation in Energy Systems: From the Paris Agreement to Energy Security*. Routledge.
2. Porter, M.E., & Kramer, M.R. (2019). *Creating Shared Value: Rethinking Corporate Sustainability*. Harvard Business Review.
3. Lutsey, N., & Sperling, D. (2018). *Policy Impact on EV Market Expansion: Analysis of Global Trends*. Journal of Transportation Research, 45(3), 187-203.
4. European Commission. (2020). *Renewable Energy Directive II*. Brussels: EU Publications.
5. U.S. Environmental Protection Agency (EPA). (2019). *CAFE Standards and Their Impact on Vehicle Emissions*. Washington, D.C.
6. Plötz, P., & Funke, S. (2017). *The Role of Policy in Advancing EV Technology Adoption: A Comparative Study*. Energy Policy, 105(2), 152-164.
7. FDA. (2021). *Green Pharmaceuticals: New Regulatory Guidelines*. Washington, D.C.
8. European Medicines Agency (EMA). (2022). *Sustainable R&D in Healthcare: Guidelines for the Future*. London: EMA Publications.
9. U.S. Environmental Protection Agency (EPA). (2021). *The Clean Air Act and Its Impact on Industrial Manufacturing*. Washington, D.C.
10. European Commission. (2020). *WEEE Directive and Its Impact on European Manufacturing*. Brussels: EU Publications.

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Application of Mössbauer Spectroscopy for Study of Hyperfine and Magnetic Properties of Ferrite Nanoparticles

Subhrajyoti Dey*
Department of Physics, Swami Vivekananda University, Barrackpore, West Bengal, India

***Corresponding Author:** dey.sjd@gmail.com

Abstract

Mössbauer spectroscopic technique is an authentic tool to investigate the magnetic and hyperfine characteristics of iron containing spinel ferrites nanoparticle systems for the last few decades. Its capability to investigate the local environment of iron nuclei makes it particularly suitable for studying the hyperfine, magnetic and structural properties of spinel ferrites at the nanoscale. ^{57}Fe Mössbauer spectroscopic technique is a nondestructive technique which can deliver detailed observation on the oxidation state and electronic and magnetic environments of iron ions of nanosized spinel ferrites which is very crucial for understanding their nanoscale properties. In this review, we explore the various applications of Mössbauer spectroscopy in characterizing ferrite nanoparticles, providing insights into their magnetic and electronic behavior, which are critical for tailoring their properties for specific applications.

Introduction

Ferrites are iron containing magnetic materials that have gathered substantial research interest for the past few decades not only due to their unique physicochemical properties but also for their novel application possibilities in different technological sectors [1 – 3]. The general formula of spinel ferrite is AB_2O_4, where A and B stand for divalent and trivalent metallic cations, respectively [1]. There are two types of crystallographic sites in the crystal structure of ferrites - tetrahedral (A) and octahedral [B] sites [2]. Tetrahedral (A) sites are generally occupied by divalent metal cations, whereas the octahedral [B] site is usually occupied by trivalent cations. Based on the distribution of divalent and trivalent metal ions among the tetrahedral (A) and octahedral [B] sites, spinel ferrites are classified as normal spinel, inverse spinel and mixed spinel structures. $ZnFe_2O_4$ and $CoFe_2O_4$ are typical examples of normal and inverse spinel structures, respectively [1]. On the other hand, $(M_{1-x}^{2+}Fe_x^{3+})_A[M_x^{2+}Fe_{2-x}^{3+}]_BO_4$ (where, $0 < x < 1$ and M represents the metallic ions) represents the structural formula for mixed spinel ferrites. It is well known that the proper choice and selection of metallic cation and their relative distribution among the (A) and [B] sites of the spinel lattice give rise to unique magnetic properties of the spinel ferrites that enhances their application possibilities in diverse technological fields [1,2].

It is well known that the exchange interactions amongst the magnetic cations in spinel type ferrites are intermediated by oxygen anions and usually, the exchange integrals J_{AA}, J_{BB} and J_{AB} are negative suggesting the presence of antiferromagnetic interaction inside the spinel ferrite structure [1]. The J_{AB} interaction between (A) and [B] site magnetic ions is significantly stronger compared to the J_{AA} and J_{BB} interaction among the cations of the same interstitial sites [1]. The dominance of J_{AB} interaction over the J_{AA} and J_{BB} interaction promotes antiparallel arrangement of the spins in different (A) and [B] sublattice which leads to frustration in the system as the spin orientation in dissimilar sublattices cannot satisfy all exchange interactions simultaneously [1]. In case of the occupation of all the (A) and [B] sites by magnetic cations we can have non-compensated magnetic moment giving rise to ferrimagnetic ordering [1]. Earlier studies suggests that the dilution of magnetic ions by incorporation of non-magnetic cations may lead to diverse kind of magnetic ordering like non-collinear spin structure, spin glass like behavior, canted ferrimagnetism etc [1, 4-7]. Moreover, it is well established that the nanoscale magnetic properties of spinel ferrites are dependent upon their crystallite size, shape, morphology, relative cation distribution etc. which in turn are very much sensitive to the synthesis route [8]. At nanoscale, spinel ferrites display superparamagnetism and spin canting effect which are responsible for the reduction of magnetization and requires to be overcome for their successful technological applications [8]. Therefore the detail study of magnetic and hyperfine properties of nanosized spinel ferrites is very much important for their fruitful application in magnetic data storage devices, electronic devices, biomedical field (hyperthermia treatment and in MRI technique), catalysis, data processing devices etc. [2].

In this context, it is pertinent to mention that Mössbauer spectroscopic technique which relies on recoilless emission and absorption of gamma ray, has become an authentic analytical tool to investigate the magnetic and hyperfine characteristics of iron containing spinel ferrites nanoparticle systems [9-12]. Its capability to investigate the local environment of iron nuclei makes it particularly suitable for studying the hyperfine, magnetic and structural properties of spinel ferrites at the nanoscale. ^{57}Fe Mössbauer spectroscopy is very much sensitive to the presence of iron which makes it a powerful technique for the detection of low concentration of irons in various types of compounds [13]. Moreover, Mössbauer spectroscopic technique is a nondestructive technique which can deliver detailed observation on the oxidation state and electronic environments of iron ions of nanosized spinel ferrites which is very crucial for understanding their nanoscale properties [14]. In this review, we explore the various applications of Mössbauer spectroscopy in characterizing ferrite nanoparticles, providing insights into their magnetic and electronic behavior, which are critical for tailoring their properties for specific applications.

Principles of Mössbauer Spectroscopy

Mössbauer spectroscopy is a well-known nuclear gamma ray spectroscopic technique which works on the basis of Mössbauer effect where gamma rays are emitted and absorbed by nuclei without any loss of energy due to recoil effect [15]. The technique is named after the German physicist Rudolf Mössbauer, who discovered the phenomenon of recoil-free gamma-ray emission and absorption and won the Nobel prize in Physics in 1961. The Mössbauer effect have been observed in several isotopes, but it is mostly associated with the iron-57 (^{57}Fe) and therefore successfully have been used to study the hyperfine and magnetic properties of different types of iron containing materials for last few decades [16 – 20]. The Mössbauer spectroscopic techniques can provide some valuable information on different types of hyperfine interactions in nanosized ferrite systems. The key hyperfine parameters are listed below:

- **Isomer Shift**

Isomer shift is an important parameter of Mössbauer spectroscopy. In the context of the gamma ray absorption, isomer shift indicates change in the electronic density. The origin of isomer shift rests in the differences in the electrostatic potential experienced by the nucleus when it is in different chemical environments or oxidation states. The isomer shift can provide insights into the oxidation state, chemical state, local electronic environment of the sample under investigation [13 – 15].

- **Quadrupole Splitting**

Quadrupole splitting is the splitting of the absorption lines of the Mössbauer spectrum due to the interaction between the nuclear quadrupole moment and the electric field gradient produced by surrounding charges in the material [13, 15]. This splitting results in distinct energy levels for the nuclear states, which can be measured as separate absorption peaks in the Mössbauer spectrum and we can gather information on the symmetry of the local electronic environment.

- **Magnetic Hyperfine Splitting**

Hyperfine magnetic splitting refers to the splitting of Mössbauer absorption lines into multiple components as a result of the interaction between the nuclear magnetic dipole moment and the magnetic field at the nucleus [13, 15]. This interaction results in separate energy levels for different nuclear states which produces multiple absorption peaks (generally a six finger pattern referred as sextet) in the Mössbauer spectrum. From the hyperfine splitting we can investigate the magnetic ordering and nature of spin states of iron atoms.

Mössbauer spectroscopy is well-accepted for the magnetic and hyperfine characterization of ferrite nanoparticles as it can reveal details about their phase purity, oxidation states, and the distribution of iron ions between different crystallographic sites (e.g., tetrahedral and octahedral sites in spinel ferrites).

Instrumentation of Mössbauer Spectroscopy

Mössbauer spectroscopic study is an effective tool for investigation of the hyperfine properties of iron containing magnetic nanomaterials [2]. Mössbauer spectroscopic technique has very small characteristic experimental time (about ~10 ns) which enable us to probe the magnetic ordering of a system with fast relaxation time. For ^{57}Fe Mössbauer spectroscopic study generally 14.4 KeV γ-ray is used. The Mössbauer spectrometer consists of a radioactive gamma ray source, an absorber, a gamma ray detector, a Mössbauer velocity transducer (MVT), a drive amplifier, a digital function generator, a pre-amplifier, a linear amplifier and a multi channel analyzer card (MCA) compatible to any PCI slot on the motherboard of a standard computer. The single channel analyzer required for energy window setting is incorporated within the MCA card. In this experimental arrangement, the absorber is at rest and a Doppler motion to the source is imparted by an electrical signal, generated by the function generator. This electrical signal converts into the mechanical motion by the MVT of the Mössbauer Drive System. The deviation of the actual motion of the driving unit from the ideal waveform is minimized by using a feed back control circuit using negative feedback. The combination of a driving coil and a pick up coil is used for this purpose. The γ-rays transmitted through the absorber are detected by Xenon filled proportional counter coupled to a standard γ-ray pulse height spectrometry system. A high voltage unit is used to supply power to the proportional counter. During the experiment the voltage was set at a stable high value. A high voltage cable is used to feed the voltage to the proportional counter. The signal received in the detector is fed to a multichannel analyzer through a preamplifier and an active filter linear pulse amplifier. The single channel analyzer incorporated in the MCA card is used to select the 14.4 KeV γ-rays of the ^{57}Co source. The digital function generator supplies the triangular reference signal to the Mössbauer driving circuit, which in turn provides the parabolic waveform required for the source motion.

The function generator supplies the synchronous start signal that starts the MCS recording and the channel advance signals that shifts the channels in a regular sequence establishing a linear correspondence with the velocity of the drive and channel number. This renders the channel number in the Mössbauer spectrum becomes proportional to the velocity of the drive. The experimental data is recorded in the multi channel scaling (MCS) mode. In this mode, the channels are opened one by one very precisely with the help of a built in timer and hence accumulation of counts in a particular channel for a preset time (t_m) is done. After the t_m interval, that particular channel is closed and the next one is opened and the process continues until the entire available channels are scanned. After that entire sequence of operation repeats and the count increases. The velocity of the drive is a known function of time and is directly related to the channel number. The Mössbauer spectra of the sample are generally recorded in transmission geometry using constant acceleration drive with a radioactive ^{57}Co source mounted in Rh matrix. The measurement temperatures of the sample are maintained within ± 0.5 K using closed cycle refrigerator, designed for Mössbauer work. The vibration free stand is used here for precise data recording. The velocity calibration of the spectrometer for our purpose is generally done with natural iron absorber at ambient temperature. The Mössbauer spectra are generally analyzed by fitting them with a suitable program (like Recoil) [2, 21]. The dynamic lineshape site analysis, Lorentzian site analysis and Voigt based site analysis methods of the Recoil program are employed to fit the Mössbauer spectra [2, 21].

Application of Mössbauer Spectroscopy for Ferrite Nanoparticles

- **Phase Composition and Purity**

Mössbauer spectroscopic technique is a useful tool for determination of phase composition of ferrite nanoparticles, especially for distinguishing phases having different type of irons [22]. Mössbauer spectroscopy can differentiate between for example between hematite (α-Fe_2O_3), magnetite (Fe_3O_4) and maghemite (γ-Fe_2O_3) samples which are some commonly observed phases of iron oxide nanoparticles [23]. The ability of quantitative measure of these phase is crucial for probing nanosized magnetic ordering of spinel ferrites.

- **Cation Distribution in Spinel Ferrites**

It is well known that in nanosized ferrites relative distribution of magnetic cations in tetrahedral (A) and octahedral [B] sites strongly influences the magnetic property of the system. The infield Mössbauer spectroscopic study is an authenticate tool for correctly probing the distribution of iron ions in (A) and [B] site of the spinel lattice [8-11]. The infield Mössbauer spectra are generally recorded in presence of high external magnetic field parallel to the gamma ray direction as the overlapping of hyperfine sextets ascribed to tetrahedral (A) and octahedral [B] site prevents accurate estimation of relative distribution of iron ions [8]. The Mössbauer spectrum in presence of external field gets clearly resolved as the hyperfine magnetic fields at (A) and [B] sites get added and subtracted, respectively [8] and we can quantitatively measure the relative Fe^{3+} ions distribution among (A) and [B] sites [8].

- **Magnetic Properties and Hyperfine Interactions**

Mössbauer spectroscopy is very much helpful to elucidate the diverse kind of magnetic ordering in nanosized ferrite systems. Mössbauer spectroscopy have been successfully applied to investigate and measure superparamagnetic relaxation of fine particle system [24]. Probing superparamagnetism is of primary interest as it is very much important for application of ferrites in bio-medical fields like hyperthermia treatment and magnetic resonance imaging (MRI). The infield Mössbauer spectrum can easily identify ferrimagnetic ordering in spinel ferrites [8].

- **Probing Surface Effects**

Surface effects plays a major role in determining nanoscale magnetic properties of spinel ferrites due to their high surface-to-volume ratio compared to their bulk counterpart [8]. The surface regions may experience different electronic and magnetic environment that can be probed by Mössbauer spectroscopic technique. For example, non collinear spin structure or spin canting effect is a common feature of nanosized spinel ferrites [8]. By using infield Mössbauer spectroscopic technique and fitting the spectrum one can quantitatively measure the amount of spin canting both at core and surface region of nanoparticles [2, 25].

- **Temperature-Dependent Studies**

Mössbauer spectroscopy can be easily conducted over a wide range of temperatures, starting from high temperature to liquid helium temperature. This makes it an ideal technique for studying temperature-dependent magnetic transitions in ferrite nanoparticles. The variation of superparamagnetic relaxation with temperature and the strengthening of magnetic ordering with the lowering of temperature can be easily studied in nanosized spinel ferrites by recording and analyzing Mössbauer spectra at different temperature [24]. The Verwey transition in magnetite (the transition from an insulating to a conducting phase) can also be detected using Mössbauer spectroscopy [26].

Conclusion

Mössbauer spectroscopy is a well-established powerful and versatile tool for studying magnetic ordering and hyperfine properties of ferrite nanoparticles. Its ability to probe the local environment of iron atoms provides detailed insights into phase composition, cation distribution, magnetic properties, and surface effects, all of which are critical for optimizing the performance of ferrite nanoparticles in various applications. In this review a short discussion on basic aspects and applicability of

Mössbauer spectroscopic technique for the characterization of spinel ferrite have been discussed.

References

1. S. Dey, S.K. Dey, S. Majumder, A. Poddar, P. Dasgupta, S. Banerjee and S. Kumar, Physica B: Condens. Matter 448 (2014) 247.
2. S. Dey, S. K. Dey, B. Ghosh, P. Dasgupta, A. Poddar, V. R. Reddy and S. Kumar, J. Appl. Phys. 114 (2013) 093901-1.
3. A. Goldman, Modern Ferrite Technology (Van Nostrand, Reinhold, New York, 1990).
4. S. A. Oliver, H. H. Hamdeh and J. C. Ho, Phys. Rev B 60 (1999) 3400.
5. Y. Yafet and C. Kittel, Physical Review 87 (1952) 290.
6. J L Dormann and M Nogues, J. Phys.: Condens. Matter 2 (1990) 1223.
7. J. M. D. Coey, Can. J. Phys. 65 (1987) 1210.
8. B. Ghosh, S. Kumar, A. Poddar, C. Mazumdar, S. Banerjee, V. R. Reddy and A. Gupta, J. Appl. Phys. 108 (2010) 034307.
9. K. Sarkar, M. Dutta, R. Mondal, S. Dey, S. Majumder, N. Sepay, U.C. Halder and S. Kumar, Materials Today Communication 39 (2024) 108953.
10. S. Ammar, N. Jouini, F. Fievet, Z. Beji, L. Smiri, P. Moline, M. Danot and J-M Greneche, J. Phys.: Condens. Matter 18 (2006) 9055.
11. C. N. Chinnasamy, A. Narayanasamy, N. Ponpandian, K. Chattopadhyay, H Guerault and J-M Greneche, J. Phys.: Condens. Matter 12 (2000) 7795.
12. R. N. Bhowmik, R. Ranganathan, R. Nagarajan, B. Ghosh, and S. Kumar, Phys Rev B 72 (2005) 094405-1 – 094405-10.
13. N. N. Greenwood and T. C. Gibb, Mössbauer Spectroscopy (Springer Netherlands, 1971)
14. E. Kuzmann, Z. Homonnay, Z. Klencsár and R. Szalay, Molecules 26 (2021) 1062.
15. P. Gutlich, E. Bill and A. X. Trautwein, Mössbauer spectroscopy and Transition Metal Chemistry – Fundamentals and Applications (Springer, 2011).
16. J. G. Stevens, L. H. Bowen and K. M. Whatley, Anal. Chem. 60 (1988) 90.
17. R. B. Scorzelli and E. dos Santos, Geochemistry, 79 (2019) 125547.
18. G. J. Long and F. Grandjean, Mössbauer Spectroscopy Applied to Magnetism and Materials Science: Volume 2 (Kluwer Academic/Plenum Publishers, 1996)
19. P. Gutlich, Zeitschrift Für Anorganische Und Allgemeine Chemie, 638(1) (2011) 15.
20. R. Zboril, M. Mashlan and D. Petridis, Chem. Mater. 14 (2002) 969.

21. K. Lagarec and D. G. Rancourt, Recoil—Mossbauer Spectral Analysis Software for Windows (University of Ottawa Press, Ottawa, 1998).

22. M. Tsvetkov, M. Milanova, I. Ivanova, D. Neov, Z. Cherkezova-Zheleva, J. Zaharieva and M. Abrashev, Journal of Molecular Structure 1179 (2019) 233

23. L. Machala, J. Tucek, and R. Zboril, Chem. Mater. 23 (2011) 3255.

24. S. Dey, S.K. Dey, B. Ghosh, V.R. Reddy and S. Kumar, Mater Chem Phys 138 (2013) 833.

25. V. Sepelak, I. Bergmann, A. Feldhoff, P. Heitjans, F. Krumeich, D. Menzel, F. J. Litterst, S. J. Campbell and K. D. Becker, J. Phys. Chem. C 111 (2007) 5026.

26. V. Chlan, J. Zukrowski, A. Bosak, Z. Kakol, A. Kozłowski, Z. Tarnawski, R. Reznícek, H. Štepánková, P. Novák, I. Biało and J. M. Honig, Phys Rev B 98 (2018) 125138.

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Water Quality Prediction Using Machine Learning: A Smart Approach for Real-Time Monitoring

Abhijit Paul[1*] Rishabh Pipalwa[2]
[1]Department of Computer Science, Swami Vivekananda University, Barrackpore, India.
[2]Senior Consultant, Aaseya IT services pvt ltd, Hyderabad, Telangana, India.

***Corresponding Author:** abhijitp@svu.ac.in

Abstract

Water quality is crucial for public health, agriculture, and industrial applications. With increasing pollution and contamination threats, traditional water quality monitoring methods are insufficient to provide real-time insights and early warnings. This paper proposes a machine learning-based framework for predicting water quality parameters, such as pH, dissolved oxygen (DO), turbidity, and chemical composition. The system leverages Internet of Things (IoT) sensors for real-time data collection and uses supervised learning algorithms to predict water quality levels based on historical data. Experimental results demonstrate that machine learning models, particularly Random Forest and Support Vector Machines (SVM), achieve high prediction accuracy and can provide early warnings for water contamination, making the system suitable for both industrial and residential applications.

Introduction

Water quality monitoring is essential to ensure safe drinking water, prevent environmental pollution, and maintain ecosystem health. However, traditional water quality testing relies on manual sampling, laboratory analysis, and periodic testing, which may fail to detect real-time contamination events or provide timely warnings. The increase in industrial discharge, agricultural runoff, and urbanization has further heightened the risk of water contamination, making it imperative to adopt more sophisticated monitoring methods.

Recent advancements in IoT and machine learning (ML) technologies offer an opportunity to develop predictive models that provide continuous water quality monitoring and early warnings. IoT sensors can collect real-time data on multiple water quality parameters, such as pH, dissolved oxygen (DO), turbidity, and total dissolved solids (TDS). Machine learning algorithms can process this data to predict future water quality levels and identify potential risks before they become critical. This paper presents a framework that integrates IoT sensors and machine learning models to predict water quality and enable proactive management of water resources.

Literature Review

- **Traditional Water Quality Monitoring**

Traditional water quality monitoring involves manual sampling, laboratory analysis, and intermittent testing at specific points in time. While this method can provide accurate results, it suffers from significant delays, high costs, and limited coverage. According to Zhang et al. (2018), these limitations prevent traditional methods from effectively detecting real-time contamination events, particularly in remote or rural areas where testing facilities may be scarce.

- **IoT-Enabled Water Monitoring Systems**

The integration of IoT technology into water monitoring has gained significant attention in recent years. IoT-enabled sensors can provide continuous real-time monitoring of various water quality parameters, such as pH, temperature, DO, and turbidity, transmitting the data to centralized systems for analysis. Research by Khattak et al. (2020) demonstrated that IoT-based systems can significantly improve the detection of water quality issues by providing timely data that is not subject to manual delays. Despite their advantages, these systems often lack the predictive capabilities needed for proactive water management.

- **Machine Learning for Predictive Water Quality Models**

Machine learning has proven effective in analyzing time-series data and predicting complex patterns, making it well-suited for water quality prediction. Studies have applied supervised learning algorithms, such as Random Forest, Support Vector Machines (SVM), and Neural Networks, to predict water quality parameters. For instance, Lee et al. (2019) used Random Forest models to predict DO levels in river water, achieving high prediction accuracy by accounting for seasonal and environmental variations.

Similarly, deep learning models such as Long Short-Term Memory (LSTM) networks have been employed to forecast water quality trends based on historical data . Although these models provide accurate predictions, they require large datasets and significant computational power, which may limit their application in resource-constrained environments.

- **Real-Time Water Quality Prediction Systems**

Some recent works have combined IoT sensors and machine learning models to enable real-time water quality prediction. For example, a study by Nawaz et al. (2020) developed an IoT-based system for predicting pH levels in drinking water using SVM. The system provided early detection of contamination events and helped users take preventive measures. However, many such systems are focused on specific parameters and lack a holistic approach to predicting multiple water quality indicators simultaneously.

- **Overview**

The proposed system integrates IoT sensors and machine learning algorithms to predict water quality in real-time. The architecture consists of three main components:

  - **IoT Sensor Network:** A set of water quality sensors deployed in the field to measure parameters such as pH, temperature, turbidity, DO, and TDS.
  - **Data Processing and Storage:** A cloud-based platform that collects and preprocesses the sensor data before feeding it into machine learning models for prediction.
  - **Machine Learning Models:** A suite of ML algorithms trained on historical water quality data to predict future water quality levels and detect anomalies.

- **IoT Sensor Network**

The IoT sensor network is responsible for collecting real-time data on key water quality parameters. Sensors are deployed in water bodies, such as rivers, lakes, or reservoirs, as well as industrial or municipal water systems. These sensors measure pH, temperature, DO, TDS, and other relevant parameters and transmit the data to the cloud via wireless communication protocols like LoRa or Wi-Fi . A study by Shaikh et al. (2019) showed that IoT sensors could provide accurate and continuous data collection, making them suitable for real-time water quality monitoring.

- **Data Processing and Preprocessing**

The raw sensor data is collected in real-time and transmitted to a cloud-based platform, where it undergoes preprocessing. Preprocessing steps include removing noise, handling missing values, and normalizing the data to account for variations in sensor readings. This ensures that the data is clean and suitable for machine learning models. For example, in a water body where seasonal changes can affect water quality, normalization ensures that the data from different seasons can be compared effectively.

- **Machine Learning Algorithms**

The system employs a combination of machine learning models for water quality prediction. The following algorithms are utilized:

- **Random Forest (RF):** Random Forest is a robust ensemble learning method that creates multiple decision trees and averages their predictions to provide reliable and accurate forecasts. RF is particularly effective in predicting water quality parameters that are influenced by multiple environmental factors, such as temperature, pH, and DO.
- **Support Vector Machines (SVM):** SVM is used to classify water quality into different categories, such as "safe," "moderate," and "contaminated," based on multiple parameters. SVM's ability to create clear decision boundaries makes it ideal for binary or multi-class classification problems, such as determining whether the water quality meets safety standards .3. LSTM Networks: For time-series forecasting, LSTM networks are employed to predict future water quality trends based on historical data. LSTM can capture long-term dependencies in the data, making it useful for predicting gradual changes in water quality over time, such as seasonal variations or the impact of climate change.

- **Cloud Platform and User Interface**

The cloud platform stores both historical and real-time data for model training and analysis. It also hosts a user interface, typically a web or mobile application that provides users with real-time insights into water quality parameters. The platform displays graphical representations of water quality trends, alerts users when predicted values exceed safety thresholds, and provides recommendations for corrective actions, such as filtration or chemical treatment.

Methodology

- **Data Collection and Preprocessing**

Data was collected from multiple water bodies over a one-year period, covering a wide range of environmental conditions. Each sample included measurements of pH, turbidity, temperature, DO, and TDS. The data was then preprocessed to handle missing values, outliers, and noise. For instance, sensor malfunctions that resulted in erroneous readings were filtered out to improve model performance.

- **Model Training and Evaluation**
  - **Training Phase:** During training, historical water quality data was used to train the Random Forest, SVM, and LSTM models. The data was divided into training and test sets, with 80% of the data used for training and 20% for validation. Hyperparameter tuning was performed using grid search to optimize the performance of each model.
  - **Evaluation Metrics:** The models were evaluated using several metrics, including mean absolute error (MAE) for regression tasks (e.g., predicting DO or turbidity levels), and accuracy, precision, and recall for classification

tasks (e.g., classifying water as "safe" or "contaminated"). Cross-validation was employed to ensure that the models could generalize well to unseen data.

- **Real-Time Prediction**

In the operational phase, the system continuously collects real-time data from the sensors and uses the trained models to predict water quality parameters. The predictions are updated frequently, allowing the system to provide real-time warnings if any parameters deviate from safe levels. When the predicted values indicate contamination or water quality deterioration, the system triggers an alert through the user interface .

Results and Discussion

The system was tested on real-world data from water bodies in both urban and rural environments. The following results were observed:

- **Accuracy of Prediction:** The Random Forest model outperformed the other models in predicting water quality parameters, achieving an accuracy of 95% in predicting pH and DO levels. SVM was effective in classifying water quality into different safety categories with an accuracy of 92%. LSTM provided reliable forecasts of future water quality trends, though its performance slightly declined in datasets with high seasonal variation.
- **Early Detection of Contamination:** The system successfully identified early signs of contamination, such as a sudden drop in DO levels, allowing users to take preventive actions before the water quality deteriorated further. This demonstrates the system’s potential for real-time monitoring and proactive management of water resources.

Conclusion

This paper presents a smart water quality prediction system that combines IoT sensors with machine learning algorithms to provide real-time monitoring and early warnings of water contamination. The system was shown to be highly effective in predicting key water quality parameters, such as pH, DO, turbidity, and TDS, with Random Forest and SVM models achieving the best results. The proposed solution offers a scalable, cost-effective approach to water quality monitoring for both industrial and residential applications. Future research could explore the integration of additional environmental variables, such as rainfall and agricultural runoff, to further improve prediction accuracy.

References

1. Zhang, H., et al. (2018). "Limitations of Traditional Water Quality Monitoring: Challenges and Opportunities." Journal of Water Resources.
2. Khattak, H., et al. (2020). "IoT-Based Water Quality Monitoring Systems: A Review." Environmental Monitoring and Assessment.

3. Lee, J., et al. (2019). "Predicting Dissolved Oxygen Levels in River Water Using Random Forest." International Journal of Water Resources Management.
4. Nawaz, F., et al. (2020). "IoT and Machine Learning for pH Prediction in Drinking Water Systems."IEEE Internet of Things Journal.
5. Shaikh, A., et al. (2019). "IoT Sensors for Real-Time Water Quality Monitoring."Sensors and Actuators.

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Integrating Circular Economy Principles into Sustainable Research and Development

Sourav Saha*
Swami Vivekananda University, Kolkata, West Bengal India.

***Corresponding Author:** sourav@svu.ac.in

Abstract

The increasing awareness of environmental degradation and resource depletion has spurred the adoption of circular economy (CE) principles as a means of promoting sustainable development. By minimizing waste, extending product life cycles, and fostering resource efficiency, CE offers a systematic framework that redefines production and consumption patterns. This paper explores the integration of CE principles into sustainable research and development (R&D) processes. The focus is on the transformation of linear economic models into circular systems, and the role that innovation in R&D plays in facilitating this transition. Case studies, current methodologies, and policy approaches are discussed to demonstrate the feasibility of CE-driven sustainable R&D.

Introduction

The linear economic model, which is predominantly characterized by a 'take, make, dispose' approach, has led to the unsustainable consumption of resources and significant environmental impacts. The circular economy (CE) model emerges as a response to these challenges, seeking to redesign economic systems by closing material loops and extending the life cycles of products. Research and development (R&D) in the context of sustainability can play a pivotal role in supporting this transition. By incorporating CE principles into R&D, industries can innovate new materials, technologies, and processes that support a sustainable and regenerative economy.

The aim of this paper is to discuss the integration of circular economy principles into sustainable R&D, emphasizing the importance of innovation in creating resource-efficient, waste-minimizing, and closed-loop systems. This integration is necessary to address global challenges such as resource scarcity, environmental degradation, and climate change.

Circular Economy Principles

The circular economy is based on the following principles:

- **Design Out Waste and Pollution:** Products and services are designed to reduce waste and pollution at every stage of the lifecycle, from material sourcing to end-of-life.
- **Keep Products and Materials in Use:** CE encourages the reuse, repair, remanufacture, and recycling of products and materials, thus extending their utility.
- **Regenerate Natural Systems:** Circular processes aim to restore and regenerate ecosystems, which are often degraded by linear economic activities (Ellen MacArthur Foundation, 2020).

These principles shift the focus from consumption to regeneration, transforming waste into resources and preserving the value embedded in materials. The integration of these principles into sustainable R&D is critical for fostering innovation that aligns with the CE agenda.

The Role of R&D in Promoting a Circular Economy

R&D is a cornerstone of innovation and can serve as the driving force behind the transition to a circular economy. Sustainable R&D encompasses not only the creation of new technologies but also the rethinking of product design, production processes, and business models. The integration of CE principles into R&D promotes sustainable resource use, increases energy efficiency, and reduces the environmental footprint of industrial activities. [1]

- **Materials Innovation**

One of the primary areas where CE principles can be integrated into R&D is through materials innovation. Developing sustainable materials that are recyclable, biodegradable, or derived from renewable sources is essential for closing the loop on resource use. For instance, researchers are exploring bio-based plastics, which have the potential to replace conventional fossil-based plastics, thus reducing dependency on non-renewable resources (Zhao et al., 2021). [2]

- **Product and Process Redesign**

Another crucial aspect of sustainable R&D is the redesign of products and processes to enhance their circularity. This can involve improving product durability, modularity, and ease of repair, making them more adaptable to new uses over time. Additionally, innovations in production processes, such as additive manufacturing and modular construction, can reduce material waste and energy consumption (Bocken et al., 2016). [4]

- **Business Model Innovation**

The CE framework encourages the adoption of new business models, such as product-as-a-service, which shifts the focus from ownership to access. Sustainable R&D can play a key role in developing technologies and systems that support these business models, such as digital platforms for product sharing and tracking material flows within supply chains (Tukker, 2015). [3]

Case Studies in CE and Sustainable R&D

Numerous organizations are integrating CE principles into their R&D efforts, leading to groundbreaking innovations that contribute to sustainability.

- **Philips: Circular Lighting Solutions**

Philips, a global leader in lighting, has embraced CE principles through its development of circular lighting solutions. Instead of selling lighting products, Philips offers light as a service, where customers pay for the light, they use while Philips retains ownership of the equipment. This approach ensures that products are returned at the end of their life cycle, allowing the company to recycle components and minimize waste (Ellen MacArthur Foundation, 2017). [5]

- **Interface: Sustainable Carpet Manufacturing**

Interface, a flooring manufacturer, has been a pioneer in incorporating CE principles into its operations. Through its "Mission Zero" initiative, Interface aimed to eliminate any negative environmental impact by 2020. This involved extensive R&D in the development of recyclable materials, waste minimization strategies, and closed-loop manufacturing processes (Anderson, 2011). [1]

- **Veolia: Resource Recovery and Circular Water Management**

Veolia, a global provider of environmental services, integrates CE principles into its R&D to promote circular water management. By developing technologies for wastewater treatment and resource recovery, Veolia helps to reduce water consumption and recycle valuable materials such as phosphorus and biogas from waste streams (Veolia, 2019).

Policy and Regulation Supporting CE-Driven R&D

Governments and regulatory bodies are increasingly recognizing the importance of CE in fostering sustainability. Policies that promote CE often incentivize R&D in areas such as waste reduction, recycling, and resource efficiency.

- **European Union Circular Economy Action Plan**

The European Union (EU) has implemented a Circular Economy Action Plan, which encourages member states to adopt CE practices in industries ranging from electronics to plastics. This policy framework provides funding for R&D projects focused on innovative circular solutions, such as the Horizon 2020 program, which supports research on sustainable materials, energy-efficient technologies, and circular business models (European Commission, 2020).

- **China's Circular Economy Promotion Law**

China, one of the world's largest economies, has also embraced CE principles through its Circular Economy Promotion Law. This law incentivizes companies to reduce resource consumption, recycle waste materials, and develop environmentally friendly technologies. The Chinese government has allocated significant funding to support R&D initiatives in areas such as green manufacturing and resource recovery (Zhu et al., 2019).

Challenges and Future Directions

Despite the progress made, there are challenges in fully integrating CE principles into sustainable R&D. These include technological limitations, financial constraints, and the need for stronger collaboration across sectors. Future research should focus on developing scalable circular solutions, improving material traceability, and fostering cross-industry partnerships.

Furthermore, policy interventions should continue to provide incentives for businesses and researchers to prioritize circularity in their R&D efforts. The transition to a circular economy requires a collective effort involving governments, businesses, researchers, and consumers.

Conclusion

Integrating circular economy principles into sustainable research and development is essential for addressing the environmental and economic challenges of the 21st century. By fostering innovation in materials, product design, and business models, R&D can drive the transition to a regenerative and resource-efficient economy. The adoption of CE principles in R&D not only enhances environmental sustainability but also offers economic opportunities for businesses through the creation of new markets and value chains. As policy frameworks and technological advancements continue to evolve, the potential for CE-driven R&D to transform industries and societies is becoming increasingly evident.

References

1. Anderson, R. C. (2011). *Business Lessons from a Radical Industrialist*. St. Martin's Press.
2. Bocken, N. M. P., de Pauw, I., Bakker, C., & van der Grinten, B. (2016). Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering*, 33(5), 308–320.
3. Ellen MacArthur Foundation. (2017). *Circular Economy in Detail: Philips Circular Lighting*. Retrieved from Ellen MacArthur Foundation website.
4. Ellen MacArthur Foundation. (2020). *The Circular Economy in Detail*. Retrieved from Ellen MacArthur Foundation website.
5. European Commission. (2020). Circular Economy Action Plan: For a Cleaner and More Competitive Europe. Retrieved from European Commission website.
6. Tukker, A. (2015). Product services for a resource-efficient and circular economy – A review. *Journal of Cleaner Production*, 97, 76-91.
7. Veolia. (2019). *Circular Water Management*. Retrieved from Veolia website.
8. Zhao, X., Cornish, K., & Vodovotz, Y. (2021). Narrowing the gap for bioplastic use in food packaging: An update. *Environmental Science & Technology*, 55(13), 7999–8015.
9. Zhu, J., Ma, X., & Huang, Y. (2019). China's circular economy: Towards a green, low-carbon and resource-efficient future. *Journal of Environmental Management*, 231, 137-145.

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Green Fluid Power: Innovations in Renewable Energy Integration and Efficiency

Ranjan Kumar*
Swami Vivekananda University, Barrackpore, Kolkata, India.

***Corresponding Author:** ranjansinha.k@gmail.com

Abstract

The fluid power industry, traditionally dependent on fossil fuels, is experiencing a transformation driven by the urgent need for sustainability. Green fluid power technologies, which focus on reducing energy consumption and integrating renewable energy sources, are gaining prominence. This article reviews recent advancements in green fluid power systems, focusing on hydraulic and pneumatic technologies. Innovations in energy-efficient designs, energy recovery, and the integration of renewable energy sources like solar and wind are discussed. The review highlights key research developments and identifies challenges and future directions for making fluid power systems more efficient and sustainable.

Introduction

Fluid power, encompassing hydraulic and pneumatic systems, plays a vital role in various industries, including manufacturing, agriculture, construction, and transportation. These systems are essential for converting mechanical energy into fluid pressure and vice versa. However, fluid power systems are traditionally energy-intensive and often rely on fossil fuels, leading to significant inefficiencies and environmental concerns.

The shift toward sustainability is prompting innovation in green fluid power, which aims to enhance energy efficiency and reduce the carbon footprint of fluid power systems by incorporating renewable energy. This paper reviews the latest advancements in energy-efficient fluid power technologies and the integration of renewable energy sources. The focus is on how these innovations are helping industries transition toward more sustainable operations.

Overview of Fluid Power Systems

- **Hydraulic Systems**

Hydraulic systems use pressurized fluid to generate mechanical motion or force. They are widely used in applications requiring high power density, such as construction equipment, industrial machinery, and aerospace. Hydraulic systems typically consist of a pump, valves, actuators, and fluid reservoirs. While efficient in power transmission, these systems are known for their high energy consumption due to friction losses, fluid leaks, and heat generation (Esposito, 2018).

- **Pneumatic Systems**

Pneumatic systems use compressed air to generate motion or force. They are favored for applications that require lower power and cleaner operations, such as automation in food processing and packaging industries. Pneumatic systems tend to be less efficient than hydraulics, mainly due to energy losses during the compression and expansion of air (Shearer et al., 2007).

The Environmental Impact of Traditional Fluid Power

Traditional fluid power systems rely heavily on fossil fuels to generate the energy needed to power pumps and compressors. This dependence leads to significant greenhouse gas emissions, contributing to climate change. Additionally, inefficiencies in these systems, such as energy losses through heat dissipation and fluid leaks, further exacerbate their environmental impact. According to research by Manring (2013), the average hydraulic system operates at only 60–70% efficiency, with the rest of the energy lost as heat.

As industries increasingly prioritize sustainability, there is a pressing need for fluid power systems that are more energy-efficient and can be integrated with renewable energy sources. This shift is giving rise to green fluid power technologies that aim to minimize environmental impacts while maintaining or improving system performance.

Innovations in Green Fluid Power Technologies

- **Energy-efficient Hydraulic Systems**

Recent advancements in hydraulic system design have focused on reducing energy consumption by improving system efficiency. One such innovation is the development of variable-speed pump drives. Unlike traditional constant-speed pumps, variable-speed pumps adjust their speed based on the load demand, reducing energy consumption during low-power operations. Research by Rahmfeld and Ivantysynova

(2014) shows that variable-speed pumps can improve energy efficiency by up to 40% compared to conventional systems.

Another promising development is the use of hydraulic accumulators for energy storage and recovery. Accumulators store excess energy during low-load periods and release it during peak demand, reducing the overall energy required. This approach has been successfully applied in hybrid hydraulic systems, which combine hydraulic power with electrical or mechanical energy sources for greater efficiency (Zhu et al., 2019).

- **Energy-efficient Pneumatic Systems**

In pneumatic systems, energy recovery and storage technologies are gaining traction as a means of improving efficiency. Regenerative braking systems, for example, capture and store energy that would otherwise be lost during deceleration and braking. This energy is then reused to power pneumatic actuators, reducing the need for additional compressed air generation.

Improved compressor designs are another area of innovation. Modern compressors with variable-speed drives and better control algorithms can optimize air generation based on real-time demand, minimizing energy losses. For instance, research by Lorenz et al. (2016) highlights that advanced control systems can reduce energy consumption in pneumatic systems by as much as 30%.

- **Fluid Power and Renewable Energy Integration**

One of the most exciting developments in green fluid power is the integration of renewable energy sources, such as solar and wind, to power fluid systems. Solar-powered hydraulic systems are being explored for remote locations where access to grid electricity is limited. These systems use solar panels to generate the electricity needed to power hydraulic pumps, offering a clean and sustainable alternative to fossil fuel-powered systems (Zhang et al., 2020).

Wind energy is also being integrated into fluid power systems, particularly in offshore applications. For example, offshore wind turbines can be coupled with hydraulic systems to store excess energy during periods of high wind. This stored energy can then be used to power fluid systems during low-wind periods, ensuring continuous operation without relying on external power sources (Guo et al., 2017).

Energy Recovery in Fluid Power Systems

Energy recovery is a critical component of improving fluid power system efficiency. Hydraulic systems, for instance, often waste a significant amount of energy through heat dissipation in pressure relief valves and throttling losses. Energy recovery devices, such as hydraulic transformers and energy-recycling circuits, can capture this lost energy and reintroduce it into the system (Ivantysynova et al., 2011).

In pneumatic systems, energy recovery is typically achieved through pressure and heat recovery techniques. Heat exchangers are used to capture and reuse the heat generated during air compression, improving overall system efficiency. Pressure recovery systems, on the other hand, capture the residual pressure in exhaust air and redirect it to other parts of the system that require lower pressure levels (Shearer et al., 2007).

Environmental and Economic Benefits of Green Fluid Power

The transition to green fluid power technologies offers significant environmental and economic benefits. By improving energy efficiency and reducing reliance on fossil fuels, industries can significantly lower their carbon footprints. According to research by IEA (2019), the adoption of energy-efficient fluid power systems could reduce global CO2 emissions by 10–15% in industrial sectors by 2030.

Economically, green fluid power systems can lead to substantial cost savings over time. Reduced energy consumption translates to lower operating costs, while the integration of renewable energy sources can shield industries from the volatility of fossil fuel prices. Furthermore, energy recovery technologies can reduce the wear and tear on system components, extending their lifespan and reducing maintenance costs (Zhu et al., 2019).

Challenges and Future Directions

Despite the promising developments in green fluid power technologies, several challenges remain. The high initial costs of energy-efficient systems and renewable energy integration can be a barrier to widespread adoption, particularly for small and medium-sized enterprises. Additionally, the complexity of hybrid systems that combine hydraulic, pneumatic, and renewable energy sources requires advanced control algorithms and skilled personnel for operation and maintenance (Guo et al., 2017).

Future research should focus on further reducing the costs of green fluid power technologies, making them accessible to a broader range of industries. Additionally, the development of standardized guidelines for the design and implementation of green fluid power systems would facilitate their adoption. Finally, continued advancements in energy storage and recovery technologies are essential to maximizing the efficiency of these systems.

Conclusion

Green fluid power represents a significant step toward making fluid power systems more sustainable and energy-efficient. Through innovations in variable-speed drives, energy recovery technologies, and the integration of renewable energy sources, fluid power systems can achieve substantial reductions in energy consumption and emissions. While challenges remain, ongoing research and technological advancements promise to make green fluid power a viable solution for industries aiming to reduce their environmental impact while maintaining operational efficiency.

References

1. Esposito, A. (2018). *Fluid Power with Applications*. Pearson.
2. Guo, S., Yang, Z., & Zheng, H. (2017). Wind-hydraulic hybrid power systems for offshore applications. *Renewable Energy*, 108, 160-169.
3. IEA. (2019). *The Future of Hydrogen: Seizing Today's Opportunities*. International Energy Agency.
4. Ivantysynova, M., Rahmfeld, R., & Weber, J. (2011). Hydraulic transformers: A key technology for efficient fluid power systems. *International Journal of Fluid Power*, 12(1), 13-22.
5. Lorenz, R., Griesbaum, M., & Schuster, G. (2016). Energy-efficient compressed air systems: Analysis and control. *Pneumatics Today*, 21(2), 45-52.
6. Manring, N. D. (2013). *Hydraulic Control Systems*. John Wiley & Sons.
7. Rahmfeld, R., & Ivantysynova, M. (2014). Innovative energy-saving hydraulic systems for mobile applications. *Journal of Mechanical Design*, 136(9), 091003.
8. Shearer, J., Murphy, R., & Richardson, B. (2007). Pneumatic systems and energy efficiency: Challenges and opportunities. *Control Engineering Practice*, 15(6), 703-715.
9. Zhang, Y., Wang, X., & Li, Q. (2020). Solar-powered hydraulic systems: Design and performance analysis. *Energy Conversion and Management*, 209, 112632.
10. Zhu, Z., Li, M., & Zhang, J. (2019). Hybrid hydraulic systems: A comprehensive review. *Journal of Mechanical Engineering Science*.

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